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\*\*\* START OF THIS PROJECT GUTENBERG EBOOK ON LABORATORY ARTS \*\*\*

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ON LABORATORY ARTS

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PREFACE

EXPERIMENTAL work in physical science rests ultimately upon the

mechanical arts. It is true that in a well-appointed laboratory,

where apparatus is collected together in greater or less profusion,

the appeal is often very indirect, and to a student carrying out a set

experiment with apparatus provided to his hand, the temptation to

ignore the mechanical basis of his work is often irresistible.

It often happens that young physicists are to be found whose

mathematical attainments are adequate, whose observational powers are

perfectly trained, and whose general capacity is unquestioned, but who

are quite unable to design or construct the simplest apparatus with

due regard to the facility with which it ought to be constructed.

That ultimate knowledge of materials and of processes which by long

experience becomes intuitive in the mind of a great inventor of course

cannot be acquired from books or from any set course of instruction.

There are, however, many steps between absolute ignorance and

consummate knowledge of the mechanical arts, and it is the object of

the following pages to assist the young physicist in making his first

steps towards acquiring a working knowledge of "laboratory arts."

However humble the ambition may be, no one can be more keenly alive

than the writer to the inadequacy of his attempt; and it is only from

a profound sense of the necessity which exists for some beginning to

be made, that he has had the courage to air his views on matters about

which there are probably hundreds or thousands of people whose

knowledge is superior to his own.

Moreover, nothing has been further from the writer's mind than any

idea of "instructing" any one; his desire is--if happily it may so

befall--to be of assistance, especially to young physicists or

inventors who wish to attain definite mechanical ends with the minimum

expenditure of time. Most people will agree that one condition

essential to success in such an undertaking is brevity, and it is for

this reason that alternative methods as a rule have not been given,

which, of course, deprives the book of any pretence to being a

"treatise." The writer, therefore, is responsible for exercising a

certain amount of discretion in the selection he has made, and it is

hardly to be hoped that he has in all--or even in the majority of

cases--succeeded in recommending absolutely the best method of

procedure.

This brings another point into view. Before all things the means

indicated must be definite and reliable. It is for this reason that

the writer has practically confined himself to matters lying within

his own immediate experience, and has never recommended any process

(with one or two minor exceptions, which he has noted) which he has

not actually and personally carried through to a successful issue.

This, although it is a matter which he considers of the highest

importance, and which is his only title to a hearing, has

unfortunately led to a very personal tone in the book.

With regard to the arts treated of in the following pages, matters

about which information is easily acquired--such as carpentering,

blacksmithing, turning, and the arts of the watchmaker--have been

left on one side. With regard to the last, which is of immense use in

the laboratory, there happen to be at least two excellent and handy

books, viz. Saunier's Watchmakers' Handbook, Tripplin, London, 1892;

and Britton's Watchmakers' Dictionary and Guide.

With regard to carpentering, turning, and blacksmithing, almost any

one who so desires can obtain a little practical experience in any

village. A short chapter has been devoted to glass-blowing, in spite

of there being an excellent and handy book by Mr. Shenstone (The

Methods of Glass-blowing, Rivington) on the subject already in

existence. The reason for this exception lies in the fact that the

writer's methods differ considerably from those advocated by Mr.

Shenstone.

The chapter on opticians' work has had to be compressed to an extent

which is undesirable in dealing with so complex and delicate an art,

but it is hoped that it will prove a sufficient introduction for

laboratory purposes. In this matter the writer is under great

obligations to his friend and assistant, Mr. James Cook, F.R.A.S, who

gave him his first lessons in lens-making some twenty years ago. To

Mr. John A. Brashear of Allegheny, Pa, thanks are due for much

miscellaneous information on optical work, which is included verbatim

in the text, some of it contained originally in printed papers, and

some most kindly communicated to the writer for the purpose of this

book. In particular, the writer would thank Mr. Brashear for his

generously accorded information as to the production of those "flat"

surfaces for which he is so justly famous.

The writer is also indebted to Mr. A. E. Kennelly for some

information as to American practice in the use of insulating material

for electrical work, and to his friends Mr. J. A. Pollock and Dr. C.

J. Martin for many valuable suggestions. For the illustrations

thanks are due to Mrs. Threlfall and Mr. James Cook. With regard to

matters which have come to the writer's knowledge by his being

specifically instructed in them from time to time, due acknowledgment

is, it is hoped, made in the text.

With regard to the question as to what matters might be included and

what omitted, the general rule has been to include information which

the author has obtained with difficulty, and to leave on one side that

which he has more easily attained. All the "unities" have been

consistently outraged by a deliberate use of the English and metric

systems side by side. So long as all the materials for mechanical

processes have to be purchased to specifications in inches and feet,

it is impossible to use the centimetre consistently without

introducing inconvenience. However, everybody ought to, and probably

does, use either system with equal facility.

No attempt has been made at showing how work can be done without

tools. Though, no doubt, a great deal can be done with inferior

appliances where great economy of money and none of time is an object,

the writer has long felt very strongly that English physical

laboratory practice has gone too far in the direction of starving the

workshop, and he does not wish, even indirectly, 'to give any

countenance to such a mistaken policy. Physical research is too

difficult in itself, and students' time is too valuable, for it to be

remunerative to work with insufficient appliances.

In conclusion, the writer would ask his readers to regard the book to

some extent as tentative, and as a means to the procuring and

organising of information bearing upon laboratory arts. Any

information which can be given will be always thankfully received, and

the author hereby requests any reader who may happen to learn

something of value from the book to communicate any special

information he may possess, so that it may be of use to others should

another edition ever be called for.

CHAPTER I

HINTS ON THE MANIPULATION OF GLASS AND ON GLASS-BLOWING FOR LABORATORY

PURPOSES

§ 1. THE art of glass-blowing has the conspicuous advantage, from the

point of view of literary presentation, of being to a great extent

incommunicable. As in the case of other delightful arts--such as

those treated of in the Badminton Library, for instance--the most

that can be done by writing is to indicate suitable methods and to

point out precautions which experience has shown to be necessary, and

which are not always obvious when the art is first approached. It is

not the object of this work to deal with the art of glass-blowing or

any other art after the manner befitting a complete treatise, in which

every form of practice is rightly included. On the contrary, it is my

wish to avoid the presentation of alternative methods.

I consider that the presentation of alternative methods would, for my

present purpose, be a positive disadvantage, for it would swell this

book to an outrageous size; and to beginners--I speak from

experience--too lavish a treatment acts rather by way of obscuring

the points to be aimed at than as a means of enlightenment. The

student often does not know which particular bit of advice to follow,

and obtains the erroneous idea that great art has to be brought to

bear to enable him to accomplish what is, after all, most likely a

perfectly simple and straightforward operation.

This being understood, it might perhaps be expected that I should

describe nothing but the very best methods for obtaining any proposed

result. Such, of course, has been my aim, but it is not likely that I

have succeeded in every case, or even in the majority of cases, for I

have confined myself to giving such directions as I know from my own

personal experience will, if properly carried out, lead to the result

claimed. In the few cases in which I have to refer to methods of

which I have no personal experience, I have endeavoured to give

references (usually taking the form of an acknowledgment), so that an

idea of their value may be formed. All methods not particularised may

be assumed by the reader to have come within my personal experience.

§ 2. Returning to glass-blowing, we may note that two forms of

glass-blowing are known in the arts, "Pot" blowing and "Table"

blowing. In the former case large quantities of fluid "metal"

(technical term for melted glass) are assumed to be available, and as

this is seldom the case in the laboratory, and as I have not yet felt

the want of such a supply, I shall deal only with "table" blowing.

Fortunately there is a convenient book on this subject, by Dr.

Shenstone (Rivingtons), so that what I have to say will be as brief as

possible, consistent with sufficiency for everyday work. As a matter

of fact there is not very much to say, for if ever there was an art in

which manual dexterity is of the first and last importance, that art

is glass-working.

I do not think that a man can become an accomplished glass-blower from

book instructions merely--at all events, not without much unnecessary

labour,--but he can learn to do a number of simple things which will

make an enormous difference to him both as regards the progress of his

work and the state of his pocket.

§ 3. The first thing is to select the glass. In general, it will

suffice to purchase tubes and rods; in the case where large pieces

(such as the bulbs of Geissler pumps) have to be specially prepared by

pot-blowing, the student will have to observe precautions to be

mentioned later on. There are three kinds of glass most generally

employed in laboratories.

§ 4. Soft Soda Glass, obtained for the most part from factories in

Thuringia, and generally used in assembling chemical apparatus.--This

glass is cheap, and easily obtainable from any large firm of apparatus

dealers or chemists. It should on no account be purchased from small

druggists, for the following reasons:-

(a) It is usually absurdly dear when obtained in this way.

(b) It is generally made up of selections of different age and

different composition, and pieces of different composition, even if

the difference is slight, will not fuse together and remain together

unless joined in a special manner.

(c) It is generally old, and this kind of glass often devitrifies with

age, and is then useless for blowpipe work, though it may be bent

sufficiently for assembling chemical apparatus. Devitrified glass

looks frosty, or, in the earlier stages, appears to be covered by

cobwebs, and is easily picked out and rejected.

§ 5. It might be imagined that the devitrification would disappear

when the glass is heated to the fusing point; and so it does to a

great extent, but for many operations one only requires to soften the

glass, and the devitrification often persists up to this temperature.

My experience is that denitrified glass is also more likely to crack

in the flame than good new glass, though the difference in this

respect is not very strongly marked with narrow tubes.

§ 6. Flint Glass.

Magnificent flint glass is made both in England and France. The

English experimenter will probably prefer to use English glass, and,

if he is wise, will buy a good deal at a time, since it does not

appear to devitrify with age, and uniformity is thereby more likely to

be secured. I have obtained uniformly good results with glass made by

Messrs. Powell of Whitefriars, but I daresay equally good glass may

be obtained elsewhere.

For general purposes flint glass is vastly superior to the soft soda

mentioned above. In the first place, it is very much stronger, and

also less liable to crack when heated--not alone when it is new, but

also, and especially, after it has been partly worked. Apparatus made

of flint glass is less liable to crack and break at places of unequal

thickness than if made of soda glass. This is not of much importance

where small pieces of apparatus only are concerned, because these can

generally be fairly annealed; and if the work is well done, the

thickness will not be uneven. It is a different matter where large

pieces of apparatus, such as connections to Geissler pumps, are

concerned, for the glass has often to be worked partly in situ, and

can only be imperfectly annealed.

Joints made between specimens of different composition are much more

likely to stand than when fashioned in soda glass. Indeed, if it is

necessary to join two bits of soda glass of different kinds, it is

better to separate them by a short length of flint glass; they are

more likely to remain joined to it than to each other. A particular

variety of flint glass, known as white enamel, is particularly

suitable for this purpose, and, indeed, may be used practically as a

cement.

§ 7, It is, however, when the necessity of altering or repairing

apparatus complicated by joints arises that the advantage of flint

glass is most apparent. A crack anywhere near to a side, or inserted

joint, can scarcely ever be repaired in the case of soda glass

apparatus, even when the glass is quite thin and the dimensions small.

It should also be mentioned that flint glass has a much more brilliant

appearance than soda glass. Of course, there is a considerable

difference between different kinds of flint glass as to the melting

point, and this may account for the divergency of the statements

usually met with as to its fusibility compared with that of soda

glass. The kind of flint glass made by Messrs. Powell becomes

distinctly soft soon after it is hot enough to be appreciably luminous

in a darkened room, and at a white heat is very fluid. This fluidity,

though of advantage to the practised worker, is likely to give a

beginner some trouble.

§ 8. As against the advantages enumerated, there are some drawbacks.

The one which will first strike the student is the tendency of the

glass to become reduced in the flame of the blow-pipe. This can be

got over by proper adjustment of the flame, as will be explained later

on. A more serious drawback in exact work is the following. In

making a joint with lead glass it is quite possible to neglect to fuse

the glass completely together at every point; in fact, the joint will

stand perfectly well even if it be left with a hole at one side, a

thing which is quite impossible with soft soda glass, or is at least

exceedingly unusual. An accident of this kind is particularly likely

to happen if the glass be at all reduced. Hence, if a joint does not

crack when cold, the presumption is, in the case of soda glass, that

the joint is perfectly made, and will not allow of any leak; but this

is not the case with flint glass, for which reason all joints between

flint glass tubes require the most minute examination before they are

passed. If there are any air bubbles in the glass, especial care must

be exercised.

§ 9. Hard or Bohemian, Glass.

This is, of course, used where high temperatures are to be employed,

and also in certain cases where its comparative insolubility in water

is of importance. It is very unusual for the investigator to have to

make complicated apparatus from this glass. Fused joints may be made

between hard glass and flint glass without using enamel, and though

they often break in the course of time, still there is no reason

against their employment, provided the work be done properly, and they

are not required to last too long.

§ 10. On the Choice of Sizes of Glass Tube.

It will be found that for general purposes tubes about one-quarter

inch in inside diameter, and from one-twentieth to one-fortieth of an

inch thick, are most in demand. Some very thin soda glass of these

dimensions (so-called "cylinder" tubes) will be found very handy for

many purposes. For physico-chemical work a good supply of tubing,

from one-half to three-quarters of an inch inside diameter, and from

one-twentieth to one-eighth inch thick, is very necessary. A few

tubes up to three inches diameter, and of various thicknesses, will

also be required for special purposes.

Thermometer and "barometer" tubing is occasionally required, the

latter, by the way, making particularly bad barometers. The

thermometer tubing should be of all sizes of bore, from the finest

obtainable up to that which has a bore of about one-sixteenth of an

inch. Glass rods varying from about one-twentieth of an inch in

diameter up to, say, half an inch will be required, also two or three

sticks of white enamel glass for making joints.

To facilitate choice, there is appended a diagram of sizes from the

catalogue of a reliable German firm, Messrs. Desaga of Heidelberg, and

the experimenter will be able to see at a glance what sizes of glass

to order. It is a good plan to stock the largest and smallest size of

each material as well as the most useful working sizes.

Fig. 1.

§ 11. Testing Glass.

"Reject glass which has lumps or knots, is obviously conical, or has

long drawn-out bubbles running through the substance." If a scratch be

made on the surface of a glass tube, and one end of the scratch be

touched by a very fine point of fused glass, say not more than

one-sixteenth inch in diameter, the tube, however large it is (within

reason), ought to crack in the direction of the scratch. If a big

crack forms and does not run straight, but tends to turn

longitudinally, it is a sign that the glass is ill annealed, and

nothing can be done with it. If such glass be hit upon in the course

of blow-pipe work, it is inadvisable to waste time upon it; the best

plan is to reject it at once, and save it for some experiment where it

will not have to be heated.

The shortest way of selecting glass is to go to a good firm, and let

it be understood that if the glass proves to be badly annealed it will

be returned. Though it was stated above that the glass should not be

distinctly conical, of course allowance must be made for the length of

the pieces, and, on the other hand, a few highly conical tubes will be

of immense service in special cases, and a small supply of such should

be included.

The glass, as it is obtained, should be placed in a rack, and covered

by a cloth to reduce the quantity of dust finding its way into the

tubes. It has been stated by Professor Ostwald that tubes when reared

up on end tend to bend permanently. I have not noticed this with lead

glass well supported. Each different supply should be kept by itself

and carefully described on a label pasted on to the rack, and tubes

from different lots should not be used for critical welds. This

remark is more important in the case of soda than of lead glass.

In the case of very fine thermometer tubes it will be advisable to

cover the ends with a little melted shellac, or, in special cases, to

obtain the tubes sealed from the works. Soda glass can generally be

got in rather longer lengths than lead glass; the longer the lengths

are the better, for the waste is less.

It is useful to be able to distinguish the different kinds of glass by

the colour. This is best observed by looking towards a bright surface

along the whole length of the tube and through the glass. Lead glass

is yellow, soda glass is green, and hard glass purple in the samples

in my laboratory, and I expect this is practically true of most

samples. [Footnote: Some new lead glass I have is also almost purple

in hue. If any doubt exists as to the kind of glass, it may be tested

at once in the blow-pipe flame, or by a mixture of oils of different

refractive indices, as will be explained later.]

§ 12. The question of the solubility of glass in reagents is one of

great importance in accurate work, though it does not always meet with

the attention it deserves. It is impossible here to go into the

matter with sufficient detail, and the reader is therefore referred to

the Abstracts of the Chemical Society, particularly for the years 1889

and 1892. The memoir by F. Kohlrausch, Wied. Ann. xliv, should be

consulted in the original. The following points may be noted. A

method of testing the quality of glass is given by Mylius (C. S. J.

Abstracts, 1889, p. 549), and it is stated that the resistance of

glass to the action of water can generally be much increased by

leaving it in contact with cold water for several days, and then

heating it to 300° to 400° C. This improvement seems to be due to the

formation of a layer of moist silica on the surface, and its

subsequent condensation into a resisting layer by the heating. Mylius

(C. S. J. Abstracts, 1892, p. 411), and Weber, and Sauer (C. S.

J. Abstracts, 1892, p. 410) have also shown that the best glass for

general chemical purposes consists of:

Silica, 7 to 8 parts

Lime, 1 part

Alkali, 1.5 to 1.1 parts.

This is practically "Bohemian" tube glass.

The exact results are given in the Berichte of the German Chemical

Society, vol. xxv. An excellent account of the properties of glass

will be found in Grove's edition of Miller's Elements of Chemistry.

§ 13. Cleaning Glass Tubes.

This is one of the most important arts in chemistry. If the tubes are

new, they are generally only soiled by dust, and can be cleaned fairly

easily--first by pushing a bit of cotton waste through with a cane,

or pulling a rag through with string--and then washing with sand and

commercial hydrochloric acid. I have heard of glass becoming

scratched by this process, and breaking in consequence when heated,

but have never myself experienced this inconvenience. In German

laboratories little bits of bibulous paper are sometimes used instead

of sand; they soon break into a pulp, and this pulp has a slightly

scouring action.

As soon as the visible impurities are removed and the tube when washed

looks bright and clean, it may be wiped on the outside and held

perpendicularly so as to allow the water film to drain down. If the

tube be greasy (and perhaps in other cases) it will be observed that

as the film gets thinner the water begins to break away and leave dry

spots. For accurate work this grease, or whatever it is, must be

removed; and after trying many plans for many years, I have come back

to the method I first employed, viz. boiling out with aqua regia.

For this purpose, close one end of the tube by a cork (better than a

rubber bung, because cheaper), and half fill the tube with aqua regia;

then, having noted the greasy places, proceed to boil the liquid in

contact with the glass at these points, and in the case of very

obstinate dirt--such as lingers round a fused joint which has been

made between undusted tubes--leave the whole affair for twelve hours.

If the greasiness is only slight, then simply shaking with hot aqua

regia will often remove it, and the aqua regia is conveniently heated

in this case by the addition of a little strong sulphuric acid.

The spent aqua regia may be put into a bottle. It is generally quite

good enough for the purpose of washing glass vessels with sand, as

above explained.

However carefully a tube is cleaned before being subjected to blowpipe

operations, it will be fouled wherever there is an opening during the

process of heating, unless the extreme tip only of an oxidising flame

be employed. Even this should not be trusted too implicitly unless

an oxygas or hydrogen flame is employed.

When a tube or piece of apparatus has been cleaned by acid, so that on

clamping it vertically, dry spaces do not appear, it may be rinsed

with platinum distilled water and left to drain, the dust being, of

course, kept out by placing a bit of paper round the top. For

accurate work water thus prepared is to be preferred to anything else.

When the glass is very clean interference colours will be noticed as

the water dries away.

Carefully-purified alcohol may in some cases be employed where it is

desired to dry the tube or apparatus quickly. In this case an alcohol

wash bottle should be used, and a little alcohol squirted into the top

of the tube all round the circumference. The water film drags the

alcohol after it, and by waiting a few minutes and then adding a few

more drops of alcohol, the water may be practically entirely removed,

especially if a bit of filter paper be held against the lower end of

the tube. It is customary in some laboratories to use ether for a

final rinse, but unless the ether is freshly distilled and very pure,

it leaves a distinct organic residue.

When no more liquid can be caused to drain away, the tube may be dried

by heating it along its length, beginning at the top (to get the

advantage of the reduction of surface tension), and so on all down.

It will then be possible to mop up a little more of the rinsing

liquid. When the tube is nearly dry a loose plug of cotton wool may

be inserted at the bottom. The wool must be put in so that the fibres

lie on an even surface inside the tube, and the wool must be blown

free from dust. Ordinary cotton wool is useless, from being dusty and

the fibres short, and the same remark applies to wadding. Use nothing

but what is known as "medicated" cotton wool with a good long fibre.

The tube will usually soon dry of itself when the cover is lifted an

inch or so. If water has been used, the air-current may be assisted

by means of the water-pump, the air being sucked from the top, so that

the wool has an opportunity of acting as a dust filter; a very slow

stream of air only must be employed. For connecting the tube to the

pump, a bit of India-rubber tube about an inch in diameter, with a

bore of about one-eighth of an inch, may be employed. The end of the

rubber tube is merely pressed against the edge of the glass.

These remarks apply, with suitable modification, to all kinds of

finished apparatus having two openings. For flasks and so on, it is

convenient to employ a blowing apparatus, dust being avoided by

inserting a permanent plug of cotton wool in one of the leading tubes.

The efficiency of this method is greatly increased by using about one

foot of thin copper tube, bent into a helix, and heated by means of a

Bunsen burner; the hot air (previously filtered) is passed directly

into the flask, bottle, or whatever the apparatus may be. This has

proved so convenient that a copper coil is now permanently fastened to

the wall in one of the rooms of my laboratory.

The above instructions indicate greater refinement than is in general

necessary or proper for tubes that have to be afterwards worked by the

blow-pipe. In the majority of cases all that is necessary is to

remove the dust, and this is preferably done by a wad of cotton waste

(which does not leave shreds like cotton wool), followed by a bit of

bibulous filter paper. I would especially warn a beginner against

neglecting this precaution, for in the process of blowing, the dust

undergoes some change at the heated parts of the apparatus, and forms

a particularly obstinate kind of dirt.

In special cases the methods I have advocated for removing dirt and

drying without covering the damp surfaces with dust are inadequate,

but an experimenter who has got to that stage will have nothing to

learn from such a work as this.

§ 14. The Blow-pipe.

I suppose a small book might easily be written on this subject but

what I have to say--in accordance with the limitation imposed--will

be brief. For working lead glass I never use anything but an oxygas

blow-pipe, except for very large work, and should never dream of using

anything else. Of course, to a student who requires practice in order

to attain dexterity this plan would be a good deal too dear. My

advice to such a one is--procure good soda glass, and work it by

means of a modification of a gas blow-pipe, to be described directly.

The Fletcher's blow-pipes on long stems are generally very

inconvenient. The flame should not be more than 5 or 6 inches from

the working table at most, especially for a beginner, who needs to

rest his arms on the edge of the table to secure steadiness.

The kind of oxygas blow-pipe I find most convenient is indicated in

the sketch. (Fig. 2) I like to have two nozzles, which will slip on

and off, one with a jet of about 0.035 inch in diameter, the other of

about double this dimension. The oxygen is led into the main tube of

the blow-pipe by another tube of much smaller diameter, concentric

with the main tube (Fig. 3, at A). The oxygen is mixed with the gas

during its escape from the inner tube, which is pierced by a number of

fine holes for the purpose, the extreme end being closed up. The

inner tube may run up to within half an inch of the point where the

cap carrying the nozzle joins the larger tube.

Fig. 2.

Fig. 3.

If it is desired to use the blow-pipe for working glass which is

already fixed in position to a support, it will be found very

advantageous to use a hooked nozzle. The nozzle shown in the sketch

is not hooked enough for this work, which requires that the flame be

directed 'backwards towards the worker. With a little practice such a

flame may be used perfectly well for blowing operations on the table,

as well as for getting at the back of fixed tubes.

To warm up the glass, the gas supply is turned full on, and enough

oxygen is allowed to pass in to clear the flame. The work is held in

front of, but not touching, the flame, until it is sufficiently hot to

bear moving into the flame itself. The, work is exposed to this flame

until, in the case of lead glass, traces of reduction begin to appear.

When this point is reached the oxygen tap is thrown wide open. I

generally regulate the pressure on the bags, so that under these

circumstances the flame is rather overfed with oxygen. This condition

is easily recognised, as follows. The flame shrinks down to a very

small compass, and the inner blue cone almost disappears; also

flashes of yellow light begin to show themselves--a thing which does

not occur when the proportions of the gases are adjusted for maximum

heating effect.

For many purposes the small dimensions of the flame render it very

convenient, and the high temperature which can be attained at exact

spots enables glass to be fused together after a certain amount of

mixing, which is an enormous advantage in fusing lead glass on to hard

glass. The lead glass should not be heated hot enough to burn, but,

short of this, the more fluid it is the better for joints between

dissimilar samples.

It will be noticed that the blow-pipe can be rotated about a vertical

axis so as to throw the flame in various directions. This is often

indispensable.

§ 15. In general the oxygen flame does not require to be delivered

under so high a pressure as for the production of a lime light. In

England, I presume, most experimenters will obtain their oxygen ready

prepared in bottles, and will not have to undergo the annoyance of

filling a bag. If, however, a bag is used, and it has some advantages

(the valves of bottles being generally stiff), I find that a pressure

produced by placing about two hundredweight (conveniently divided into

four fifty-six pound weights) on bags measuring 3' x 2'6" x 2' (at the

thicker end) does very well. To fill such a bag with oxygen, about

700 grms of potassium chlorate is required.

If the experimenter desires to keep his bag in good order, he must

purify his oxygen by washing it with a solution of caustic soda, and

then passing it through a "tower" of potash or soda in sticks, and,

finally, through a calcium chloride tower. This purifying apparatus

should be permanently set up on a board, so that it may be carried

about by the attendant to wherever it is required. Oxygen thus

purified does not seem to injure a good bag--at least during the

first six or seven years:

In order to reduce the annoyance of preparing oxygen, the use of the

usual thin copper conical bottle should be avoided. The makers of

steel gas bottles provide retorts of wrought iron or steel for

oxygen-making, and these do very well. They have the incidental

advantage of being strong enough to resist the attacks of a servant

when a spent charge is being removed.

The form of retort referred to is merely a large tube, closed at one

end, and with a screw coupling at the other; the dimensions may be

conveniently about 5 inches by 10. The screw threads should be filled

with fireclay (as recommended by Faraday) before the joint is screwed

up. Before purchasing a bottle the experimenter will do well to

remember that unless it is of sufficiently small diameter to go into

his largest vice, he will be inconvenienced in screwing the top on and

off. Why these affairs are not made with union joints, as they should

be, is a question which will perhaps be answered when we learn why

cork borers are still generally made of brass, though steel tube has

long been available.

Fig. 4.

These little matters may appear very trivial--and so they are--but

the purchaser of apparatus will generally find that unless he looks

after details himself, they will not be attended to for him. Whether a

union joint is provided or not, let it be seen that the end of the

delivery tube is either small enough to fit a large rubber tube

connection going to the wash-bottle, or large enough to allow of a

cork carrying a bit of glass tube for the same purpose to be inserted.

This tube should not be less than half an inch in inside diameter.

Never use a new bottle before it has been heated sufficiently to get

rid of grease and carbonaceous dirt. A convenient oxygen-making

apparatus is shown in Fig. 4, which is drawn from "life."

§ 16. For large blow-pipe work with lead glass I recommend a system

of four simple blow-pipes, in accordance with the sketch annexed. I

first saw this system in operation in the lamp factory of the

Westinghouse Electric Company at Pittsburg in 1889, and since then I

have seen it used by an exceedingly clever "trick" glass-worker at a

show. After trying both this arrangement and the "brush flame"

recommended by Mr. Shenstone, I consider the former the more

convenient; however, I daresay that either can be made to work in

competent hands, but I shall here describe only my own choice.

[Footnote: A brush flame is one which issues from the blow-pipe nozzle

shaped like a brush, i.e. it expands on leaving the jet. It is

produced by using a cylindrical air jet or a conical jet with a large

aperture, say one-eighth of an inch. See Fig. 25.]

As will be seen, the blow-pipe really consists of four simple brass

tube blow-pipes about three-eighths of an inch internal diameter and 3

inches long, each with its gas and air tap and appropriate nozzle.

Each blowpipe can turn about its support (the gas-entry pipe) to some

extent, and this possibility of adjustment is of importance, The air

jets are merely bits of very even three-sixteenths inch glass tubing,

drawn down to conical points, the jets themselves being about 0.035

inch diameter.

Fig. 5.

The flames produced are the long narrow blow-pipe flames used in

blow-pipe analysis, and arranged so as to consist mostly of oxidising

flame. The air-supply does not require to be large, nor the pressure

high--5 to 10 inches of water will do--but it must be very regular.

The "trick" glass-blower I referred to employed a foot bellows in

connection with a small weighted gasometer, the Westinghouse Company

used their ordinary air-blast, and I have generally used a large

gas-holder with which I am provided, which is supplied by a Roots

blower worked by an engine.

I have also used a "velocity pump" blower, which may be purchased

amongst others from Gerhardt of Bonn. The arrangement acts both as a

sucking and blowing apparatus, and is furnished with two manometers

and proper taps, etc. As I have reason to know that arrangements of

this kind work very ill unless really well made, I venture to add that

the Gerhardt arrangement to which I refer is No. 239 in his

catalogue, and costs about three pounds. It hardly gives enough air,

however, to work four blow-pipes, and the blast requires to be

steadied by passing the air through a vessel covered with a rubber

sheet.

In default of any of these means being available, one of Fletcher's

foot-blowers may be employed, but it must be worked very regularly. A

table mounted with one blow-pipe made on this plan, and worked by a

double-acting bellows, is recommended for students' use. For working

flint glass, the air jet may be one-eighth of an inch in diameter and

the pressure higher--this will give a brush flame. See Fig. 25.

It will be seen, on looking at the sketch of the blowpipe system, that

the pair of blow-pipes farther from the observer can be caused to

approach or recede at will by means of a handle working a block on a

slide. It often happens that after using all four blow-pipes at once

it is necessary to have recourse to one blow-pipe only, and to do this

conveniently and quickly is rather an object. Now, in my arrangement

I have to turn off both the gas and air from the farther system, and

then put in a bit of asbestos board to prevent the nozzles being

damaged by the flame or flames kept alight. As I said before, when

some experience is gained, glassblowing, becomes a very simple art,

and work can be done under circumstances so disadvantageous that they

would entirely frustrate the efforts of a beginner. This is not any

excuse, however, for recommending inferior arrangements.

Consequently, I say that the pipes leading in gas and air should be

all branches of one gas and one air pipe, in so far as the two remote

and one proximate blow-pipe are concerned, and these pipes should come

up to the table to the right hand of the operator, and should have

main taps at that point, each with a handle at least 2 inches long.

By this arrangement the operator can instantly turn down all the

blow-pipes but one, while, if the inverse operation is required, all

the three pipes can be started at once. [Footnote: I find, since

writing the above, that I have been anticipated in this recommendation

by Mr. G. S. Ram, The Incandescent Lamp and its Manufacture, p.

114.]

The separate air and gas taps must be left for permanent regulation,

and must not be used to turn the supply on or cut it off. In some

respects this blow-pipe will be found more easy to manage than an

oxygas blow-pipe, for the glass is not so readily brought to the very

fluid state, and this will often enable a beginner who proceeds

cautiously to do more than he could with the more powerful instrument.

Though I have mentioned glass nozzles for the air supply, there is no

difficulty in making nozzles of brass. For this purpose let the end

of a brass tube of about one-eighth of an inch diameter be closed by a

bit of brass wire previously turned to a section as shown (Fig. 6),

and then bored by a drill of the required diameter, say -.035 inch. It

is most convenient to use too small a drill, and to gradually open the

hole by means of that beautiful tool, the watchmaker's "broach." The

edges of the jet should be freed from burr by means of a watchmaker's

chamfering tool (see Saunier's Watchmaker's Hand-book, Tripplin,

1882, p. 232, § 342), or by the alternate use of a slip of Kansas

stone and the broach.

Fig. 6.

The construction of this blow-pipe is so simple, that in case any one

wishes to use a brush flame, he can easily produce one simply by

changing his air jets to bits of the same size (say one-eighth to

one-sixteenth of an inch) tubing, cut off clean. To insure success,

the ends of the tubes must be absolutely plane and regular; the

slightest inequality makes all the difference in the action of the

instrument. If a jet is found to be defective, cut it down a little

and try again; a clean-cut end is better than one which has been

ground flat on a stone. The end of a tube may, however, be turned in

a manner hereafter to be described so as to make an efficient jet.

Several trials by cutting will probably have to be made before success

is attained. For this kind of jet the air-pressure must be greatly

increased, and a large Fletcher's foot-blower or, better still, a

small double-action bellows worked with vigour will be found very

suitable. A fitting for this auxiliary blow-pipe is shown in Fig. 5

at B.

Professor Roentgen's discovery has recently made it necessary to give

more particular attention to the working of soft soda glass, and I

have been obliged to supplement the arrangements described by a table

especially intended for work with glass of this character. The

arrangement has proved so convenient for general work that I give the

following particulars. The table measures 5 feet long, 2 feet 11

inches wide, and is 2 feet 9 inches high.

Fig. 7.

It is provided with a single gas socket, into which either a large or

small gas tube may be screwed. The larger tube is 5.5 inches long and

0.75 of an inch in diameter. The smaller tube is the same length, and

half an inch in diameter. The axis of the larger tube is 3.5 inches

above the table at the point of support, and is inclined to the

horizontal at an angle of 12°. The axis of the smaller tube is 2.5

inches above the surface of the table, and is inclined to the

horizontal at the same angle as the larger one.

The air jets are simply pieces of glass tube held in position by

corks. The gas supply is regulated by a well-bored tap. The air

supply is regulated by treading the bellows--no tap is requisite.

The bellows employed are ordinary smiths' bellows, measuring 22 inches

long by 13 inches wide in the widest part. They are weighted by lead

weights, weighing 26 lbs. The treadle is connected to the bellows by

a small steel chain, for the length requires to be invariable. As the

treadle only acts in forcing air from the lower into the upper chamber

of the bellows, a weight of 13 lbs. is hung on to the lower cover, so

as to open the bellows automatically.

The air jets which have hitherto been found convenient are:

for the small gas tube

(1) a tube 0.12 inch diameter drawn down to a jet of 0.032 inch

diameter for small work;

(2) plain tubes not drawn down of 0.14 inch, 0.127 inch, and -0.245

inch diameter, and for the large gas tube, plain tubes up to 0.3 inch

in diameter.

The table is placed in such a position that the operator sits with his

back to a window and has the black calico screen in front of him and

to his right. The object of the screen is to protect the workman

against draughts. The table is purposely left unscreened to the left

of the workman, so that long tubes may be treated.

§ 17. Other appliances which will be required for glass-blowing are

of the simplest character.

(1) Small corks for closing the ends of tubes.

(2) Soft wax--a mixture of bees' wax and resin softened by linseed

oil to the proper consistency, easily found by trial, also used for

temporarily closing tubes.

(3) A bottle of vaseline for lubricating.

(4) An old biscuit tin filled with asbestos in shreds, and an asbestos

towel or cloth for annealing glass after removal from the flame. As

asbestos absorbs moisture, which would defeat its use as an annealing

material, it must be dried if necessary.

(5) A Glass-Cutter's Knife. This is best made out of a fine

three-cornered file, with the file teeth almost ground out, but not

quite; it should be about 2 inches long. After the surface has been

ground several times, it may be necessary to reharden the steel. This

is best done by heating to a full red and quenching in mercury. The

grindstone employed for sharpening the knife should be "quick," so as

to leave a rough edge. I have tried many so-called glass knives "made

in Germany," but, with one exception, they were nothing like so good

as a small French or Sheffield file. In this matter I have the

support of Mr. Shenstone's experience.

(6) A wire nail, about 2 inches long, mounted very accurately in a

thin cylindrical wooden handle about 5 inches long by one-quarter of

an inch diameter, or, better still, a bit of pinion wire 6 inches

long, of which 1.5 inches are turned down as far as the cylindrical

core, An old dentists' chisel or filling tool is also a very good

form of instrument.

(7) A bit of charcoal about 3.5 inches long and 2 wide, and of any

thickness, will be found very useful in helping to heat a very large

tube. The charcoal block is provided with a stout wire handle, bent

in such a manner that the block can be held close above a large glass

tube on which the flames impinge. In some cases it is conveniently

held by a clip stand. By the use of such a slab of charcoal the

temperature obtainable over a large surface can be considerably

increased.

I have seen a wine-glass (Venetian sherry-glass) worked on a table

with four blow-pipes, such as is here described, with the help of a

block of hard wood held over the heated glass, and helping the

attainment of a high temperature by its own combustion.

(8) Several retort stands with screw clips.

(9) Some blocks of wood about 5" X 2" X 2" with V-shaped notches cut

in from the top.

(10) A strong pair of pliers.

(11) An apparatus for cleaning and drying the breath, when blowing

directly by the mouth is not allowable. The apparatus consists of a

solid and heavy block of wood supporting a calcium-chloride tube

permanently connected with a tube of phosphorus pentoxide divided into

compartments by plugs of glass wool. Care should be taken to arrange

these tubes so as to occupy the smallest space, and to have the stand

particularly stable. The exit tube from the phosphorus pentoxide

should be drawn down to form a nozzle, from, say, half an inch to

one-eighth of an inch in diameter, so as to easily fit almost any bit

of rubber tube. The entry to the calcium chloride should be

permanently fitted to about a yard of fine soft rubber tubing, as

light as possible. The ends of this tube should terminate in a glass

mouthpiece, which should not be too delicate.

As an additional precaution against dust, I sometimes add a tube

containing a long plug of glass wool, between the phosphorus pentoxide

and the delivery tube, and also a tube containing stick potash on the

entry side of the calcium chloride tube, but it may safely be left to

individual judgment to determine when these additions require to be

made. In practice I always keep the affair set up with these

additions. The communication between all the parts should be

perfectly free, and the tubes should be nearly filled with reagents,

so as to avoid having a large volume of air to compress before a

pressure can be got up.

The arrangement will be clear by a reference to Fig. 8, which

illustrates the apparatus in use for joining two long tubes. I have

tried blowing-bags, etc, but, on the whole, prefer the above

arrangement, for, after a time, the skill one acquires in regulating

the pressure by blowing by the mouth and lips is such an advantage

that it is not to be lightly foregone.

Fig. 8.

§ 18. The Table.

The system of four blow-pipes is, of course, a fixture. In this case

the table may be about a yard square, and may be covered with asbestos

mill-board neatly laid down, but this is not essential. The table

should have a rim running round it about a quarter of an inch high.

The tools should be laid to the right of the worker, and for this

purpose the blow-pipes are conveniently fixed rather to the left of

the centre of the table, but not so far as to make the leg of the

table come so close to the operator as to make him uncomfortable, for

a cheerful and contented spirit ought to be part of the glass-worker's

outfit.

The most convenient height for a blow-pipe table--with the blow-pipes

about 2 inches above the table top--is 3 feet 2 inches. Nothing is

so convenient to sit upon as a rough music-stool with a good range of

adjustment. The advantage of an adjustable seat lies in the fact that

for some operations one wants to be well over the work, while in

others the advantage of resting the arms against the table is more

important.

§ 19. Special Operations.

The preliminary to most operations before the blow-pipe, is to draw

down a tube and pull it out to a fine point. This is also the

operation on which a beginner should exercise himself in the first

instance. I will suppose that it is desired to draw out a tube about

one-quarter of an inch in diameter, with the object of closing it,

either permanently or temporarily, and leaving a handle for future

operations in the shape of the point, thin enough to cool quickly and

so not delay further work.

For this simple operation most of the glass-blower's skill is

required. The tube must be grasped between the first finger and thumb

of both hands, and held so that the part to be operated on lies evenly

between the two hands. The distance between the operator's thumbs may

conveniently vary from 2.5 to 4 inches. Releasing the grip of the

left hand, let the operator assure himself of his ability to easily

rotate the tube about its axis--by the right thumb and finger--he

will incidentally observe by the "feel" whether the tube is straight

or not.

A good deal of progress can be made from this point before the tube is

heated at all. The operator can acquire a habit of instinctively

rotating the tube by both hands, however the tube itself be moved

about in space, or however it be pushed or pulled. The habit of

constant and instinctive rotation is literally about one-third of the

whole art of glassblowing. It is unlikely, however, that the beginner

will discover that he has not got this habit, until a few failures

draw his attention to it.

The glass tube being held in position lightly yet firmly, and the

operator being sure that he feels comfortable and at his ease, and

that the blow-pipe flame (a single flame in this instance) is well

under control, the preliminary heating may be commenced. With a tube

of the dimensions given this is a very simple affair. Turn the air

partly off, or blow gently, to get a partly luminous gas flame; hold

the tube about an inch from the end of this flame, and turn it round

and round till it commences to soften.

In the case of soda glass it is usual to employ the gas flame only,

but I find that it is better in most cases to use the hot air of a

gently-blown flame, rather than have the disadvantage of the soot

deposited in the alternative operation. When the glass begins to

soften, or even before, it may be moved right into the blow-pipe

flame, and the latter may be properly urged.

It is not possible to give quite explicit and definite instructions,

applicable to every case, as to when the time is ripe for passing the

work into the flame, but the following notes will indicate the general

rules to be observed:-

(1) A thick tube must be warmed more slowly and raised to a higher

temperature than a thin tube.

(2) The same remark applies to a tube of large diameter, as compared

with one of small diameter, whatever the thickness.

(3) In the case of very large or thick tubes the hot air is

advantageously employed at first, and to complete the preliminary

heating, the luminous flame alone may be used. The object of this is

to enable the operator to judge, by the presence of soot, its

inability to deposit--or its burning off if deposited--of the

temperature of the glass, and of the equality of this temperature all

over the surface, for a large and thick tube might be heated quite

enough to enable it to be safely exposed to the full heat before it is

appreciably yielding to the fingers. In general, when the soot burns

off freely, or lead glass begins to show the faintest sign of

reduction, or soda glass begins to colour the flame, it is more than

safe to proceed.

In order to turn on the full flame the operator will form a habit of

holding the work in the left hand only, and he will also take care not

to let anything his right hand may be doing cause him to stop rotating

the tube with his left thumb and finger.

The preliminary adjustment of air or oxygen supply will enable the

change to a flame of maximum power to be made very quickly. The tube

having been introduced with constant rotation, it will soon soften

sufficiently to be worked. The beginner will find it best to decide

the convenient degree of softness by trial.

With soda glass it does not much matter how soft the glass becomes,

for it remains viscous, but with lead glass the viscosity persists for

a longer time and then suddenly gives place to a much greater degree

of fluidity. [Footnote: This is only drawn from my impressions

acquired in glass-working. I have never explicitly tested the matter

experimentally.]

It is just at this point that a beginner will probably meet with his

first difficulty. As soon as the glass gets soft he will find that he

no longer rotates the glass at the same speed by the right and left

hand, and, moreover, he will probably unconsciously bend the tube, and

even deform it, by pushing or pulling.

The second third of the art of the glass-blower consists in being able

to move both hands about, rotating a tube with each thumb and finger,

and keeping the distance between the hands, and also the speed of

rotation, constant. Nothing but long practice can give this facility,

but it is essential that it be acquired to some extent, or no progress

can be made. Some people acquire a moderate proficiency very quickly,

others, of whom the writer is one, only become reasonably proficient

by months, or even years, of practice.

Supposing that the tube is now ready to be drawn down, the operator

will remove it from the flame, and will gently pull the ends apart,

interrupting his turning as little as possible. If the tube be pulled

too hard, or if the area heated be too small (about three-eighths of

an inch in length in the case given would be proper), it will be found

that the ends of the two portions of the tube will be nearly closed at

a very sharp angle (nearly a right angle to the length of the tube),

that the ends will be thin, and that a long length of very fine tube

will be produced. To heat a short length of tube and pull hard and

suddenly is the proper way to make a very fine capillary tube, but, in

general, this is what we want to avoid.

If the operation be successfully performed, the drawn-down tube will

have the appearance exhibited, which is suitable either for

subsequently closing or handling by means of the drawn-down portion.

The straightness of the point can be obtained by a little practice in

"feeling" the glass when the tube is rotated as it cools just before

it loses its viscous condition.

When the operation is carried out properly the shoulder of the "draw"

should be perfectly symmetrical and of even thickness, and its axis

regarded as that of a cone should lie in the axis of the tube

produced. The operation should be repeated till the student finds

that he can produce this result with certainty, and he should not be

discouraged if this takes several days, or even weeks. Of course, it

is probable that within the first hour he will succeed in making a

tolerable job, but it is his business to learn never to make anything

else.

Fig. 9.

Fig. 10. Diagram of a folded end.

§ 20. Closing and blowing out the End of a Tube.

When it is desired to close the end of a particular bit of tube, this

is easily done by heating the end, and at the same time heating the

end of a waste bit of tube or rod; the ends, when placed in contact,

stick together, and a point can be drawn down as before. [Footnote:

"Point" is here used in the technical sense, i.e. it is a thin tail

of glass produced by drawing down a tube.] Having got a point, it

will be found that the thin glass cools enough to allow of the point

being handled after a few moments.

The most convenient way of reducing the point to a suitable length

(say 1.5 inch) is to fuse it off in the flame, but this must be done

neatly; if a tail is left it may cause inconvenience by catching, or

even piercing the finger and breaking off. The blow-pipe flame being

turned down to a suitable size, and the shoulder of the "draw" having

been kept warm meanwhile, let the tip of the flame impinge on a point

where the diameter is about half that of the undrawn tube, and let the

temperature be very high (Fig. 11). The tube is to be inclined to

the flame so that the latter strikes the shoulder normally, or

nearly so. Then, according to circumstances, little or much of the

glass can be removed at will by drawing off the tail (Fig. 12), till,

finally, a small drop of melted glass only, adheres to the end of the

now closed tube (Fig. 13).

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

When this is satisfactorily accomplished, heat the extreme end of the

tube most carefully and equally, holding it in such a position that

the glass will tend to flow from the bead back on to the tube, i.e.

hold the closed end up to the flame, the tube being, say, at 45

degrees to the horizontal. Then when the temperature is such as to

indicate complete softness lift the tube to the mouth, still holding

the tube pointing with its closed end a little above the horizontal,

and blow gently. A beginner almost always blows too hard.

What is wanted, of course, is a continued pressure, to give the

viscous glass time to yield gradually, if it is uniform; or else

intermittent puffs to enable the thinner parts, if there are any, to

cool more, and hence become more resisting than the thicker ones. In

any case a little practice will enable the operator to blow out a

round and even end--neither thicker nor thinner than the rest of the

tube.

§ 21. To make a Weld.

To begin with, try on two bits of glass of the same size, i.e. cut a

seven-inch length of glass in half by scratching it with the knife,

and pulling the ends apart with a slight inclination away from the

scratch. In other words, combine a small bending moment with a

considerable tensional stress. It is important to learn to do this

properly. If the proportions are not well observed, the tube will

break with difficulty, and the section will not be perpendicular to

the main length. If the knife is in good order it will make a fine

deep scratch--the feel of the glass under the knife will enable the

operator to decide when the scratch is made. The operation of cutting

large tubes will be treated further on. The two halves of the tube

being held one in each hand, and one tube closed at one end, the

extremities to be united will be warmed, and then put in the flame as

before.

Fig. 16.

There are many ways of proceeding--perhaps the easiest is as follows.

As soon as the glass shows signs of melting at the ends--and care

should be taken that much more is not heated--take both bits out of

the flame. Stop rotating for a moment, and resting the arms carefully

on the edge of the table, raise the tubes above the flame and bring

the ends swiftly and accurately together. This is a case of "sudden

death no second attempt at making the ends meet can be allowed; if

the tubes join in any other than a perfectly exact manner a kink more

or less objectionable will result. In practice the operator will

learn to bring the ends together, commencing at one point; i.e. the

axes of the tubes will be inclined at first, so as to cause adherence

at one spot only. If this is not quite "fair", then less damage is

done in moving one tube slightly up or down to get the contact exact.

The tubes will then be closed upon one another as if they were hinged

at the joint. This must be done lightly, yet sufficiently, to ensure

that the glass is actually in contact all round.

Having gone so far, replace the tubes--now one--in the flame, and

carefully rotating the glass, raise the temperature higher than in the

operation just described, in fact the higher the temperature, short of

burning the glass, the better. Take the tube out of the flame and

blow into the open end, turning constantly as before. One puff is

enough. Then turn and pull the glass apart till it is of the same

diameter and thickness throughout, and feel that it is straight as

before.

Though it is in general of high importance that the joint should be

well heated, the beginner will probably find that he "ties up" his

glass as soon as it gets really soft.

If his object is to make one joint--at any cost--then let him be

careful to use two bits of exactly the same kind of glass, and only

get the temperature up to the viscous stage. If the joint be then

pulled out till it is comparatively thin, it will probably stand (if

of soda glass); certainly, if of lead glass, though in this case it

may not be sound. In any case the joint should be annealed in the

asbestos box if practicable, otherwise (unless between narrow tubes)

with the asbestos rag. Care must be taken that the asbestos is dry.

§ 22. To weld two Tubes of different Sizes.

To do this, the diameter of the larger tube must be reduced to that of

the smaller. The general procedure described in drawing down must be

followed, with the following modification. In general, a greater

length of the tube must be heated, and it must be made hotter. The

tube is to be gradually drawn in the flame with constant turning till

the proper diameter and thickness of glass are attained.

Fig. 16.

For this operation time must be allowed if the operator's hands are

steady enough to permit of it; the shoulder should form partly by the

glass sinking in and partly by the process of drawing the hot glass

out. A shoulder properly prepared is shown in the sketch. Beginners

generally make the neck too thin on large tubes, and too thick on

smaller ones. There ought to be no great difference in thickness of

glass between the neck on the larger tube, and the smaller tube. The

diameters should be as nearly as possible alike.

Having drawn down the larger tube to a neck, take it out of the flame,

and as it cools pull and turn till the neck is of the right thickness

and is perfectly straight, i.e. make the final adjustment outside the

flame, and to that end have the neck rather too thick (as to glass)

before it is taken out. It is not necessary to wait till the neck

gets cold before the end can be cut off. Make a scratch as before--this

will probably slightly damage the temper of the file knife, but

that must be put up with. Hold the tube against the edge of the

table, so that the scratch is just above the level of the rim, and

strike the upper part a smart blow with the handle of the glass knife

rather in the direction of its length. [Footnote: A bit of hoop iron

nailed against the side of the table is a very convenient arrangement,

and it need not project appreciably above the general level of the

rim.]

Of course this applies to a tube where economy has been exercised and

the end is short. If the tail is long enough to form a handle, the

tube may be pulled apart as before. As a rule a temporary joint

between a tube and a rod is not strong enough to enable the shoulder

to be broken at the scratch by mere pulling. The ends to be welded

must be broken off very clean and true. Subsequent operations are to

be carried out as already described.

§ 23. The above operations will be easily performed on tubes up to

half an inch in diameter, if they are not too long. It is the length

of tube, and consequent difficulty in giving identity of motion with

the two hands, which make the jointing of long tubes difficult. There

are also difficulties if the tubes are very thin, have a very fine

bore or a very large diameter.

All these difficulties merely amuse a good glass-blower, but to an

experimenter who wants to get on to other things before sufficient

skill is acquired (in the movement of the hands and arms) the

following method is recommended. First, use flint glass. Then,

assuming that any drawing down has to be done, do it as well as

possible, for on this the success of the method to be described

especially depends. Be sure that the tubes to be welded are cut off

clean and are as nearly as may be of the same size at the point of

junction.

To fix the description, suppose it is desired to join two tubes (see

Fig. 8), each about one inch in diameter and a yard long. Get four

clip stands and place them on a level table. Be sure that the stands

are firm and have not warped so as to rock. In each pair of clips

place a tube, so that the two tubes are at the same height from the

table, and, in fact, exactly abut, with axes in the same straight

line. Close one tube by a cork and then fix the blowing apparatus as

shown to the other.

In such an operation as this the drying apparatus may be dispensed

with, and a rubber tube simply connected to one end of the system and

brought to the mouth. Take the oxygen blow-pipe and turn the nozzle

till the flame issues towards you, and see that the flame is in order.

Then turn down the oxygen till it only suffices to clear the smoky

flame, and commence to heat the proposed joint by a current of hot

air, moving the flame round the joint. Finally, bring to bear the

most powerful flame you can get out of the blow-pipe, and carry it

round the joint so quickly that you have the latter all hot at once.

Put down the blow-pipe, and, using both hands, press the tubes

together (which wooden clips will readily allow), and after seeing

that the glass has touched everywhere, pull the tubes a trifle apart.

Apply the blow-pipe again, passing lightly over the thin parts, if

any, and heating thicker ones; having the end of the rubber tube in

his mouth, the operator will be able to blow out thick places. When

all is hot, blow out slightly, and having taken the flame away, pull

the tubes a little apart, and see that they are straight.

Throw an asbestos rag over the joint, loosen one pair of the clamps

slightly, and leave the joint to anneal. It is important that the

least possible amount of glass should be heated, hence the necessity

of having the ends well prepared, and it is also important that the

work should be done quickly; otherwise glass will flow from the upper

side downwards and no strong joint will be obtained.

Fig. 17. Tube being opened at one end.

§ 24. To weld Tubes of very small Bore.

If the bore is not so small as to prevent the entrance of the point of

the iron nail, get the ends of the tubes hot, and open the bore by

inserting the end of the nail previously smeared over with a trace of

vaseline. Work the nail round by holding the handle between the thumb

and first finger of the right hand, the tube being similarly placed in

the left. The tube and nail should be inclined as shown in the

sketch.

Never try to force the operation; the nail soon cools the glass, so

that only a very short time is available after each heat; during this

the tube should be rotated against the nail rather than the nail

against the tube. Be careful not to heat a greater length of tube

than is necessary, or the nail will, by its component of pressure

along the tube, cause the latter to "jump up" or thicken and bulge.

Both ends being prepared, and if possible, kept hot, the weld may be

made as before, and the heating continued till the glass falls in to

about its previous thickness, leaving a bore only slightly greater

than before.

It is in operations such as this that the asbestos box will be found

of great use. As soon as one end of the weld is ready cool it in the

flame till soot deposits, and then plunge it into the asbestos. This

will cause it to cool very slowly, and renders it less likely to crack

when again brought into the flame. Turned-out ends, if the glass is

at all thick, are very liable to crack off on reheating, so that they

must be reintroduced (into the flame) with especial care. This

liability to breakage is reduced, but not eliminated, by the asbestos

annealing.

Figs. 18 and 19.

§ 25. When the bore is very fine, it is best to seal off the tubes,

and blow an incipient bulb near one end of each tube. These bulbs may

be cooled in asbestos, and cut across when cold by means of a scratch

touched at one end (Figs. 18 and 19) by a fine point of highly

incandescent glass. For details of this method see p. 46, Fig. 21.

Time is occasionally saved by blowing off the ends of the bulbs. The

details of this process will be described when the operation of making

thistle-headed tubes is dealt with.

§ 26. When the tubes are both of large diameter, long, and very thin

(cylinder tubes), a considerable amount of difficulty will be

experienced. On the whole, it is best to heat each end separately

till the glass thickens a little, anneal in the flame and in asbestos,

and then proceed as in § 22. If the ends are not quite true, it will

be found that quite a thickness of glass may be "jumped" together at

one side of the tubes, while the edges are still apart at the other.

When this looks likely to happen, incline the tubes as if the joint

were a hinge, and bend back quickly; do not simply continue to push

the tubes together in a straight line, or an unmanageable lump of

glass will be formed on one side.

If in spite of these precautions such a lump does form, proceed as

follows. Take a rod of glass, at least one-eighth of an inch thick,

and warm it in the flame at one end. Heat the imperfect joint till it

softens all round, and then bring the flame right up to the thick

part, and heat that as rapidly and locally as possible. The oxygas

flame does this magnificently. Press the heated end of the glass rod

against the thick part, and pull off as much of the lump as it is

desired to remove, afterwards blowing the dint out by a judicious

puff. Finish off as before.

§ 27. Occasionally, when it is seen that in order to produce a joint

closed all round, one side of the tube would be too much thickened, it

is better to patch the open side. For this purpose take a glass rod

about one-sixteenth inch in diameter, and turn the flame to give its

greatest effect, still keeping rather an excess of air or oxygen. See

that the side of the joint already made is kept fairly hot--it need

not be soft; interrupt any other work often enough to ensure this.

Then, directing the flame chiefly on the thin rod, begin to melt and

pull the glass over the edges of the gap. When the gap is closed get

the lump very hot, so that all the glass is well melted together, and

then, if necessary, pull the excess of glass off, as before described.

It must be remembered that this and the method of the previous section

are emergency methods, and never give such nice joints as a

manipulation which avoids them, i.e. when the ends of the tubes are

perfectly straight and true to begin with. Also note that, as the

tubes cannot be kept in rotation while being patched, it is as well to

work at as low a temperature as possible, consistently with the other

conditions, or the glass will tend to run down and form a drop,

leaving a correspondingly thin place behind.

Fig. 20.

§ 28. A very common fault in cutting a tube of about an inch in

diameter is to leave it with a projecting point, as shown. This can

be slowly chipped off by the pliers, using the jaws to crush and grind

away the edge of the projection; it is fatal to attempt to break off

large pieces of glass all at once.

§ 29. It will be convenient here to mention some methods of cutting

large tubes. With tubes up to an inch and a half in diameter, and

even over this--provided that the glass is not very thick--we may

proceed as follows: Make a good scratch about half an inch long, and

pretty deep, i.e. pass the knife backwards and forwards two or three

times. Press a point of melted glass exactly on one end of the

scratch; the glass point even when pressed out of shape should not be

as large as a button one-twelfth of an inch in diameter. If this

fails at first, repeat the operation two or three times.

Fig. 21.

If a crack does not form, touch the hot place with the cold end of the

nail. If no success is obtained, try the other end of the scratch.

If failure still pursues the operator, let him make another cut on the

opposite side of the tube and try again. In general, the tube will

yield the first or second time the hot drop of glass is applied.

Never apply the drop at the centre of the scratch, or a ragged crack,

which may run in any direction, will result. Very often, with a large

tube, the crack formed by a successful operation will only extend a

short distance. In this case it is desirable to entice the crack

round the tube, and not trust to its running straight when the tube is

pulled apart.

On the whole, the best method in this case is to employ a flame

pencil, which should be kept ready for use. This merely consists of a

bit of glass tube of about the same dimensions as an ordinary lead

pencil, drawn down to a very fine jet at one end. The jet must not be

very long or thin, or the glass will soon fuse up. A few trials will

enable the operator to get the proper proportions, which are such that

the tube has the general appearance of a pencil normally sharpened

(say with a cone of 60'). This tube is best made of hard glass.

Connect it to a gas supply by light flexible tubing, and turn down the

gas till the flame from the end of the jet is not more than one-tenth

of an inch long. Then apply the jet, beginning from the end of the

crack, and gradually draw it (the crack) round the tube. The

operation will be assisted if a rubber ring is slipped on the tube to

begin with, so that the eye has some guide as to whether the flame is

being drawn round properly or not. The ring must, of course, be far

enough away to escape the effect of the flame. The crack will be

found to follow the flame in the most docile manner, unless the tube

is thick or badly annealed. Some operators recommend a pencil of

glowing charcoal, but the flame is undoubtedly better.

§ 30. To cut very thick Tubes.

A large number of methods have been proposed, and nearly everybody has

his favourite. The following has always succeeded with me. First

mark on the tube, by means of a little dead black spirit paint,

exactly where the cut is to be. Then sharpen the glass knife and

scratch a quite deep cut all round: there is no difficulty in making

the cut one-twentieth of an inch deep. It will be proper to lubricate

the knife with kerosene after the first mark is made. [Footnote: The

edge of the knife may be advantageously saved by using an old file

moistened with kerosene for the purpose. I find kerosene is not

worse, but, if anything, better than the solution of camphor in

turpentine recommended by Mr. Shenstone.]

If the glass is about one-eighth of an inch thick, the scratch maybe

conveniently about one-twentieth of an inch deep, but if the glass is

anything like one-quarter of an inch thick, the scratch must be much

deeper, in fact, the glass may be half cut through. To make a very

deep scratch, a wheel armed with diamond dust, which will be described

later on, may be used. However, it is not essential to use a diamond

wheel, though it saves time.

When the cut is made to a sufficient depth proceed thus: Obtain two

strips of bibulous paper or bits of tape and twist them round the tube

on each side of the scratch, allowing not more than one-eighth of an

inch between them. Then add a few drops of water to each, till it is

thoroughly soaked, but not allowing water to run away. Dry out the

scratch by a shred of blotting paper.

Turn down the oxygas flame to the smallest dimensions, and then boldly

apply it with its hottest part playing right into the nick and at a

single point. Probably in about two seconds, or less, the tube will

break. If it does not, rotate the tube, but still so that the flame

plays in the nick. After making the tube very hot all round--if it

has not broken--apply the flame again steadily at one point for a few

seconds and then apply a bit of cold iron. If the tube does not break

at once during these processes, let it cool, and cut the groove

deeper; then try again. [Footnote: This method is continually being

reinvented and published in the various journals. It is of unknown

antiquity.]

Fig. 22.

If the tube breaks after great heating and long efforts, it will

probably leave incipient cracks running away from the break, or may

even break irregularly. A good break is nearly always one that was

easily made. If a number of rings have to be cut, or a number of cuts

made on glass tubes of about the same size, it will be found

economical in the end to mount a glazier's diamond for the purpose. A

simple but suitable apparatus is figured (Fig. 23).

Fig. 23.

The only difficulty is to regulate the position of the diamond so that

it cuts. In order to do this, carefully note its cutting angle by

preliminary trials on sheet glass, and then adjust the diamond by

clamps, or by wriggling it in a fork, as shown. Weight the board very

slightly, so as to give the small necessary pressure, and produce the

cut by rotating the tube by hand. When a cut is nearly completed take

great care that the two ends join, or irregularity will result. This

is not always easy to do unless the tube happens to be straight.

Having got a cut, start a crack by means of a fine light watchmaker's

hammer, or even a bit of fused glass, and entice the crack round the

cut by tapping with the hammer or by means of the flame pencil.

If the cut is a true "cut" the tube will break at once. As a supply

of electrical current for lighting will, in the near future, be as

much a matter of course for laboratory purposes as a gas supply, I add

the following note. To heat a tube round a scratch, nothing--not

even the oxygas blow-pipe--is so good as a bit of platinum or iron

wire electrically heated. If the crack does not start by considerable

heating of the glass, stop the current, unwind the wire, and touch the

glass on the crack either with a bit of cold copper wire or a wet

match stem. I prefer the copper wire, for in my experience the water

will occasionally produce an explosion of cracks. On the other hand,

the cold wire frequently fails to start a crack.

Judging from the appearance of thick tubes as supplied by the dealers,

the factory method of cutting off appears to be to grind a nick almost

through the tube, and right round; and for really thick glass this is

the safest but slowest way; a thin emery wheel kept wet will do this

perfectly. Suitable wheels may be purchased from the "Norton" Emery

Wheel Co. of Bedford, Mass, U.S.A.--in England through Messrs.

Churchill and Co. of London, importers.

§ 31. To blow a Bulb at the End of a Tube.

I must admit at once that this is a difficult operation--at all

events, if a large bulb is required. However, all there is to be said

can be said in few words. In general, when a bulb is required at the

end of a tube it will be necessary to thicken up the glass. A

professional glass-worker will generally accomplish this by "jumping

up" the tube, i.e. by heating it where the bulb is required, and

compressing it little by little until a sufficient amount of glass is

collected. The amateur will probably find that he gets a very

irregular mass in this way, and will be tempted to begin by welding on

a short bit of wide and thick tubing preparatory to blowing out the

bulb.

However, supposing that enough glass is assembled by-either of these

methods, and that it is quite uniform in thickness, let the thickened

part be heated along a circle till it becomes moderately soft, and let

it then be expanded about one-fifth, say by gently blowing. It is

perhaps more important to keep turning the glass during bulb-blowing

than in any other operation, and this both when the glass is in the

flame and while the bulb is being blown. It is also very important to

avoid draughts. In general, a bulb is best blown with the tube in a

nearly horizontal position, but sloping slightly upwards from the

mouth. If it be noticed that a bulb tends to blow out more at one

side than another, let the side of greatest protuberance be turned

down, so that it is at the lowest point, reduce the pressure for an

instant, and then blow again. It will be observed that the bulb will

now expand at the top.

The reason of this is chiefly that the under side cools most rapidly

(according to Faraday, Chemical Manipulation, § 1194), and

consequently can expand no further; but also it is not unlikely that

the glass tends to flow somewhat from the upper side, which remains

hot, and consequently the bulb, when the next puff reaches it, will

tend to yield at this point. By heating several zones the tube will

become gradually expanded.

Fig. 24.

Fig. 25.

Fig. 26.

When the length of the thickened part of the tube only slightly

exceeds its diameter (Fig. 25), let the whole be brought to a

temperature which, with flint glass, should be just short of that of

perfect fluidity; and then, holding the tube horizontally and

constantly turning it, let the bulb be blown out to its full size,

noting the appearances and correcting too great protuberance on any

side by the means above mentioned. If the bulb appears pear-shaped

turn the tube so that the melted mass is directed upwards; if the

bulb have the contrary fault, correct in the corresponding manner.

The bulb when finished may be lightly tapped on the table, when, if

there is any weak place owing to inequality of thickness, the bulb

will break, and the operation may be started afresh. "A good bulb is

round, set truly on the tube, and free from lumps of thick glass or

places of excessive thinness." When the amateur has succeeded in

blowing a bulb two inches in diameter on the end of a strong bit of

thermometer tube--say for an air thermometer--he may well seek the

congratulations of his friends.

In case the bulb is not satisfactory on a first attempt, it may be

melted down again, if the following precautions are taken. Directly

creases begin to appear in the bulb let it be withdrawn from the

flame, and gently blown till the creases come out. By alternate

heating and blowing the glass can be got back to its original form, or

nearly so, but unless the operator shows great skill and judgment, the

probability is that the glass will be uneven. By heating and keeping

the thicker parts in the higher position, and blowing a little now and

again, the glass may be got even, and a new attempt may be made. It

must not be supposed that this process can be carried on indefinitely,

for the glass tends to lose its viscous properties after a time, or,

at all events, it "perishes" in some way, especially if it has been

allowed to get very thin; consequently too frequent attempts on the

same glass are unprofitable. Two or three trials are as many as it

generally pays to make. As a rule the largest possible flame may be

used with advantage in this operation.

§ 32. To blow a bulb in the middle of a tube, the procedure is much

like that already treated, but the manipulation is, if anything,

more difficult, for the further end of the tube must be carried and

turned as well as the end which is held to the lips.

§ 33. To make a side Weld.

This is by no means difficult, but is easier with lead glass than with

soda glass. The tube to which it is desired to make a side connection

having been selected, it is closed at one end by rubber tube stops, or

in any other suitable manner. The zone of the proposed connection is

noted, and the tube is brought to near softness round that circle (if

the tube is made actually soft, inconvenience will arise from the

bending, which is sure to occur). Two courses are then open to the

operator, one suitable to a thick tube, the other to a tube of

moderate thickness.

Taking the former first. Provide a piece of glass rod and warm its

end. Direct a small flame against the spot on the thick tube where

the proposed joint is to be. When the glass becomes almost

incandescent at this spot, put the end of the rod against it and draw

out a thread of glass till sufficient "metal" has been removed. Then

fuse off the thread close to the tube.

Fig. 27.

The subsequent procedure is the same as for thin tubes. In this case

heat the spot by the smallest flame available, and get the spot very

hot. Blow it out gently into a bubble, perhaps extending to a height

equal to its diameter. Then heat the top of the bubble till it is

incandescent and blow violently. This will produce an opening fringed

by glass so thin as to exhibit interference colours. Remove the filmy

part, and heat the frayed edges till they cohere and form an incipient

tube. If the flame has been of a correct size, the tube will now be

of the same diameter as the tube to be welded on, and will project

perhaps one-sixteenth of an inch from the surface of the main tube

(Fig. 28).

Fig. 28.

Fig. 29.

When this stage is reached, again heat the tube all round till it

nearly softens, and by means of the other hand heat the end of the

other tube which it is proposed to weld. Just before the main tube

actually softens, turn it so as to heat the edges of the aperture, and

at the same time get the end of the side tube very hot. Take both out

of the flame for an instant, and press the parts together, instantly

slightly withdrawing the side tube. If the operation is well

performed, it will be found that the point of maximum thickness of

glass is now clear of the main tube. The joint is then to be heated

all round and blown out--a rather awkward operation, and one

requiring some practice, but it can be done.

Fig. 30.

If great strength is wanted, heat the main tube all round the joint

bit by bit, and blow each section slightly outwards. If the operator

is confident in his skill, he should then heat the whole joint to the

softening point, blow it out slightly, and then adjust by pulling and

pushing. Cool first in the gas flame, and then plunge the joint into

the asbestos and cover it up--or if too large, throw the asbestos

cloth round it.

In the case of soda glass this final "general heat" is almost

essential, but it is not so with flint glass, and as the general heat

is the most difficult part of the job, it will be found easier to use

lead glass and omit the general heating. With soda glass a very small

irregularity will cause the joint to break when cold, but flint glass

is much more long-suffering. It is easy to perform the above

operation on small tubes. For large ones it will be found best to

employ flint glass and use the clip stands as in the case of direct

welds, treated above, but, of course, with suitable modifications.

Never let the main tube cool after the hole is made until the work is

done.

§ 34. Inserted Joints.

In many instances the performance of apparatus is much improved by

joints of this kind, even when their use is not absolutely essential.

There are two ways in which inserted joints may be made. The first

method is the easier, and works well with flint glass; but when one

comes to apply it to soda glass there is a danger of the glass

becoming too thick near the joint, and this often leads to a cracking

of the joint as the glass cools.

Fig. 31.

Suppose it is desired to insert the tube B into the tube A (Fig. 31).

Begin by reducing the size of the end of tube A till B will just slip

in quite easily. With B about one-quarter inch in diameter, a

clearance of about one-twentieth of an inch, or less, in all (i.e.

one-fortieth of an inch on each side) will be proper.

Heat B by itself at the proposed zone of junction, and blow out a very

narrow ring; then compress this slightly so that it forms an almost

closed ring of glass. The figure refers to the close of this

operation (Fig. 31, B). It does not matter much whether the ring

remains a mere flattened bulb, or whether it is a solid ring, but it

must be one or the other. Some judgment must be exercised in

preparing the ring. In general, the beginner will collect too much

glass in the ring, and consequently the joint, when made, will either

be thick and liable to crack easily, or it will be blown out into an

erratic shape in endeavours to reduce this thickness. Accordingly,

the operator will, if necessary, thin the tube B by drawing slightly,

if he considers it desirable, before the little enlargement is blown

out. In general, two heats must be used for this operation.

Fig. 32.

Get the approximating parts of both A and B up to a temperature just

below that at which they will adhere, and having closed the other end

of A, place B carefully within it up to the ring, and if it can be

arranged, have a mica wad in A, with a central hole through which the

end of B can project. This will very much facilitate the operation,

especially if B is long, but may be dispensed with by the exercise of

care and skill.

The operation is now simple. Fuse the junction and press the tubes

lightly together, being careful not to collect more glass than can be

helped; finally, blow out the joint and reduce the thickness by mild

drawing (Fig. 33). In order to make a really good joint, two points

must be particularly attended to--the rim must be thin and its plane

perfectly perpendicular to the axis of tube B; the end of tube A must

be cut off quite clean and perpendicular to its axis before B is

inserted. So important are these conditions--especially the latter

that the writer has even occasionally used the grindstone to get the

end of A into a proper condition, an admission which will probably

earn the contempt of the expert glass-worker.

Fig. 33.

Now for the second method, which is often practised in Germany, where

soda glass is chiefly used. With this glass the chief point is to get

a very even and not too thick ring at the junction, and consequently

the extra thickening produced by making a rim on B is rather a

drawback. The method consists in cutting off from B the length which

it is desired to insert, slipping this into A (which may be an

otherwise closed bulb, for instance), and then gradually melting up

the open end of A till the piece of B inside will no longer fall out.

By holding the joint downwards so that the inserted portion of B rests

on the edges of the opening, a joint may be made with the minimum

thickening.

The external part of B, previously heated, is then applied, and the

joint subjected to a "general" heat and blown out. Very nice joints

may be made by this method, and it is perhaps the better one where the

external part of B is to be less in diameter than the inserted part.

It was in this manner that the writer was taught to make glass

velocity pumps, one of which, of a good design, is figured as an

example.

In all cases good annealing should follow this operation. If the

inserted part of the inner tube (B) is anything like an inch in

diameter, and especially if it is of any length, as in some forms of

ozone apparatus, or in a large Bunsen's ice calorimeter, the

arrangements for supporting the inner part must be very good. A

convenient way of proceeding when the inner tube is well supported is

to make the mouth of A only very little larger than the diameter of B,

so that B will only just slip in. Then the mouth of A and the zone of

B may be heated together, and B blown out upon A. This, of course,

must be arranged for, if necessary, by temporarily stopping the inner

end of B.

The inner support of B should be removed as soon as practicable after

the joint is made, or, at all events, should not be perfectly rigid; a

tightly-fitting cork, for instance, is too rigid. The reason is, of

course, that in cooling there may be a tendency to set B a little to

one side or the other, and if it is not free to take such a set, the

joint most probably will give way. Good annealing both with flame and

asbestos is a sine qua non in all inserted work.

Fig. 34.

§ 35. Bending Tubes.

I have hitherto said nothing about bending tubes, for to bend a tube

of a quarter of an inch in diameter, and of ordinary thickness, is

about the first thing one learns in any laboratory, while to bend

large tubes nicely is as difficult an operation as the practice of

glass-blowing affords. However, even in bending a narrow tube it is

possible to proceed in the wrong way. The wrong way is to heat a

short length of the tube and then bend it rapidly, holding the plane

of the bend horizontal. The right way, per contra, is to use a

batswing burner to heat, say, two inches of the tube with constant

turning till it is very soft, and then, holding the glass so that the

bend will be in a vertical plane passing through one eye (the other

being shut), to make the bend rather slowly.

If an exact angle is required, it is as well to have it drawn out on a

sheet of asbestos board. In this case bend the glass as described

till it is approximately right, and finish by laying it on the

asbestos board and bringing it up to the marks. A suitable bit of

wood may be substituted for the asbestos on occasion.

N.B: The laboratory table is not a suitable piece of wood. A

right-angled bend is often wanted. In this case the corner of a table

will serve as a good guide to the eye, the glass being finished by

being held just above it. If great accuracy is wanted, make a wooden

template and suspend it by a screw from the side of the table, so that

the vertex of the gauge for the interior angle projects downwards,

then finish by bending the tube round it. The wood may be about half

an inch thick.

If a sharp bend is required, heat the tube in the blow-pipe, and bend

it rapidly, blowing out the glass meanwhile. The reason why a long

bend should be held in a vertical plane is that the hot part tends to

droop out of the plane of the bend if the latter be made in a

horizontal position. To bend a tube above half an inch in diameter is

a more or less difficult operation, and one which increases in

difficulty as the diameter of the tube increases.

A U-tube, for instance, may be made as follows: Use the four

blow-pipe arrangement so as to heat a fair length of tube, and get,

say, two inches of tube very hot--almost fluid, in fact--by means of

the carbon block supported from a stand. Remove the tube rapidly from

the flame and draw the hot part out to, say, three inches. Then,

holding the tube so as to make the bend in a vertical plane, bend it

and blow it out together to its proper size.

This operation seems to present no difficulties to experienced

glass-workers, even with tubes of about one inch in diameter, but to

the amateur it is very difficult. I always look on a large U-tube

with feelings of envy and admiration, which the complex trick work of

an elaborate vacuum tube does not excite in the least. It will be

noted that this method may, and often does, involve a preliminary

thickening of the glass.

With tubes over an inch in diameter I have no idea as to what is the

best mode of procedure--whether, for instance, a quantity of sand or

gas coke might not be used to stuff out the tube during bending, but

in this case there would be the difficulty of removing the fragments,

which would be sure to stick to the glass.

Of course, if the bend need not be short, the tube could be softened

in a tube furnace and bent in a kind of way. I must admit that with

tubes of even less than one inch in diameter I have generally managed

best by proceeding little by little. I heat as much of the glass as I

can by means of a gigantic blow-pipe, having a nozzle of about an inch

in diameter, and driven by a machine-blower.

When I find that, in spite of blowing, the tube begins to collapse, I

suspend operations, reheat the tube a little farther on, and so

proceed. If by any chance any reader knows a good laboratory method

of performing this operation, I hope he will communicate it to me.

After all, the difficulty chiefly arises from laboratory heating

appliances being as a rule too limited in scope for such work.

The bending of very thin tubes also is a difficulty. I have only

succeeded here by making very wide bends, but of course the blowing

method is quite applicable to this case, and the effect may be

obtained by welding in a rather thicker bit of tube, and drawing and

blowing it till it is of the necessary thinness. This is, however, a

mere evasion of the difficulty.

§ 36. Spiral Tubes.

These are easily made where good heating apparatus is available. As,

however, one constantly requires to bend tubes of about one-eighth

inch in diameter into spirals in order to make spring connections for

continuous glass apparatus, I will describe a method by which this is

easily done. Provide a bit of iron pipe about an inch and a quarter

in outside diameter. Cover this with a thick sheath of asbestos

cloth, and sew the edges with iron wire. Hammer the wire down so that

a good cylindrical surface is obtained. Make two wooden plugs for the

ends of the iron pipe. Bore one to fit a nail, which may be held in a

small retort clip, and fasten a stout wire crank handle into the other

one. Support the neck of the handle by means of a second clip. In

this way we easily get a sort of windlass quite strong enough for our

purpose.

Fig. 35.

Provide a large blow-pipe, such as the blow-pipe of a Fletcher

crucible furnace, Select a length of tubing and clean it. Lash one

end to the cylinder by means of a bit of wire, and hold the other end

out nearly horizontally. Then start the blow-pipe to play on the tube

just where it runs on to the asbestos cylinder, and at first right up

to the lashing. Get an attendant to assist in turning the handle of

the windlass, always keeping his eye on the tube, and never turning so

fast as to tilt the tube upwards. By means of the blow-pipe, which

may be moved round the tubing, heat the latter continuously as it is

drawn through the flame, and lay it on the cylinder in even spirals.

If the tubing is thin, a good deal of care will have to be exercised

in order to prevent a collapse. A better arrangement, which, however,

I have not yet tried, would, I think, be to replace the blow-pipe by

two bats-wing burners, permanently fastened to a stand, one of them

playing its flame downwards on to the top of the flame of the other.

The angle between the directions of the jets might be, say, 130°, or

whatever is found convenient. In this way the glass would not be so

likely to get overheated in spots, and better work would doubtless

result. However, I have made numbers of perfectly satisfactory

spirals as described. Three or four turns only make a sufficiently

springy connection for nearly all purposes.

§ 37. On Auxiliary Operations on Glass:-

Boring Holes through Glass:- This is much more easily done than is

generally supposed. The best mode of procedure depends on the

circumstances. The following three cases will be considered:-

1. Boring holes up to one-quarter inch diameter through thick glass

(say over one-eighth inch), or rather larger holes through thin glass.

2. Boring holes of any size through thick glass.

3. Boring round holes through ordinary window glass.

§ 38. Boring small Holes.

Take a three-cornered file of appropriate dimensions, and snip the

point off by means of a hammer; grind out most of the file marks to

get sharp corners. Dip the file in kerosene, and have plenty of

kerosene at hand in a small pot. Place the broken end of the file

against the glass, and with considerable pressure begin to rotate it

(the file) backwards and forwards with the fingers, very much as one

would operate a bradawl against a hard piece of wood. The surface of

the glass will shortly be ground away, and then the file bradawl will

make much quicker progress than might be expected. Two or three

minutes should suffice to bore a bit of sheet window-glass.

The following points require attention:

(1) Use any quantity of oil.

(2) After getting through the skin reduce the pressure on the file.

(3) Be sure to turn the file backwards and forwards through a complete

revolution at least.

(4) When the hole is nearly through reduce the pressure.

(5) When the hole is through the glass be exceedingly careful not to

force the file through too rapidly, otherwise it will simply act as a

wedge and cause a complete fracture.

(6) In many cases it is better to harden the file in mercury before

commencing operations; both files and glass differ so much in hardness

that this point can only be decided by a trial. If it is found

necessary to harden the file, use either a large blow-pipe and a coke

or charcoal bed, or else a small forge. A small blowpipe, such as is

generally found in laboratories, does more harm than good, either by

burning the end of the file or raising it to an insufficient

temperature.

(7) To sharpen the file, which is often necessary after passing

through the "skin" of the glass, put it in a vice so that the point

just protrudes clear of the jaws. Then, using a bit of waste iron as

an intermediary anvil or punch, knock off the least bit from the

point, so as to expose a fresh natural surface. The same result may

be brought about by the use of a pair of pliers.

If several holes have to be bored, it is convenient to mount the file

in the lathe and use a bit of flat hard wood to press up the glass by

means of the back rest. A drilling machine, if not too heavy, does

very well, and has the advantage of allowing the glass to remain

horizontal so that plenty of oil can be kept in the hole.

Use a very slow speed in either case--much slower than would be used

for drilling wrought iron. It is essential that the lubricant should

flow on to the end of the file very freely, either from a pipette or

from the regular oil-feed. If a little chipping where the file

pierces the back surface is inadmissible, it is better, on the whole,

to finish the bore by hand, using a very taper file. It is not

necessary to use a special file for the lathe, for a well-handled file

can be chucked very conveniently in a three-jaw chuck by means of the

handle.

Mr. Shenstone recommends a lubricant composed of camphor dissolved in

turpentine for general purposes. With the object of obtaining some

decisive information as to the use of this lubricant, and to settle

other points, I made the following experiments. Using an old

three-cornered French file, I chipped off the point and adjusted the

handle carefully. I also ground out the file marks near the point,

without hardening the file in mercury. Using kerosene and turpentine

and camphor, I began to bore holes in a hard bit of 3/32 inch window

glass.

Each hole was bored to about one-eighth inch in diameter in four

minutes with either lubricant. After hardening the file in mercury

and using kerosene, I also required four minutes per hole. After

mounting the file in a lathe which had been speeded to turn up brass

rods of about one-half-inch diameter, and therefore ran too fast, I

required one and a half minutes per hole, and bored them right

through, using kerosene. On the whole, I think kerosene does as well

as anything, and for filing is, I think, better than the camphor

solution. However, I ought to say that the camphor-turpentine

compound has probably a good deal to recommend it, for it has survived

from long ago. My assistant tells me he has seen his grandfather use

it when filing glass.

I beg to acknowledge my indebtedness to Mr. Pye, of the Cambridge

Scientific Instrument Company, for showing me in 1886 (by the courtesy

of the Company) the file method of glass-boring; it is also described

by Faraday in Chemical Manipulation, 1228.

It is not necessary, however, to use a file at all, for the twist

drills made by the Morse Drill Company are quite hard enough in their

natural state to bore glass. The circumferential speed of the drill

should not much exceed 10 feet per minute. In this way the author has

bored holes through glass an inch thick without any trouble except

that of keeping the lubricant sufficiently supplied. For boring very

small holes watchmaker's drills may be used perfectly well, especially

those tempered for boring hardened steel. The only difficulty is in

obtaining a sufficient supply of the lubricant, and to secure this the

drill must be frequently withdrawn.

My reason for describing the file method at such length is to be found

in the fact that a Morse drill requires to be sharpened after drilling

glass before it can be used in the ordinary way, and this is often a

difficulty.

I ought to say that I have never succeeded in boring the barrel of a

glass tap by either of these methods. [Footnote: I have been lately

informed that it is usual to employ a splinter of diamond set in a

steel wire holder both for tap boring and for drilling earthenware for

riveting. The diamond must, of course, be set so as to give

sufficient clearance for the wire holder.

For methods of using and setting diamond tools see § 55. It will

suffice to say here that a steel wire is softened and filed at one end

so as to form a fork; into this the diamond is set by squeezing with

pliers. The diamond is arranged so as to present a point in the axis

of the wire, and must not project on one side of the wire more than on

the other. It is not always easy to get a fragment satisfying these

conditions, and at the same time suitable for mounting. A drop of

solder occasionally assists the process of setting the diamond.

In drilling, the diamond must be held against the work by a constant

force, applied either by means of weight or a spring. I made many

trials by this method, using a watchmaker's lathe and pressing up the

work by a weight and string, which passed over a pulley. I used about

40 ounces, and drilled a hole 3/32 in diameter in flint glass at a

speed of 900 revolutions per minute to a depth of one-eighth of an

inch in eight minutes. I used soap and water as a lubricant, and the

work was satisfactory.

Since this was set up, I have been informed by Mr. Hicks of Hatton

Garden that it is necessary to anneal glass rod by heating it up to

the softening point and allowing it to cool very slowly under red-hot

sand or asbestos before boring. If this be done, no trouble will be

experienced. The annealing must be perfect.]

§ 39. For boring large holes through thick glass sheets, or, indeed,

through anything where it is necessary to make sure that

no accident can happen, or where great precision of position and form

of hole is required, I find a boring tube mounted as shown in the

picture (Fig. 36) is of great service. Brass or iron tube borers do

perfectly well, and the end of the spindle may be provided once for

all with a small tube chuck, or the tubes may be separately mounted as

shown. A fairly high speed is desirable, and may be obtained either

by foot, or, if power is available, is readily got by connecting to

the speed cone of a lathe, which is presumably permanently belted to

the motor.

Fig. 36.

After trying tubes armed with diamond dust, as will be presently

explained, I find that emery and thin oil or turpentine, if liberally

supplied below the glass, will do very nearly as well. The tube

should be allowed to rise from the work every few seconds, so as to

allow of fresh emery and oil being carried into the circular grooves.

This is done by lifting the hinged upper bearing, the drill being

lifted by a spiral spring between the pulley and the lower bearing

shown at B. The glass may be conveniently supported on a few sheets

of paper if flat, or held firm in position by wooden clamps if of any

other shape. In any case it should be firmly held down and should be

well supported. Any desired pressure upon the drill is obtained by

weighting the hinged board A.

§ 40. The following method was shown to me by Mr. Wimshurst, but I

have not had occasion to employ it myself. It is suitable for boring

large holes through such glass as the plates of Mr. Wimshurst's

Influence machines are usually made of. A diamond is mounted as the

"pencil" of a compass, and with this a circle is drawn on the glass in

the desired position. The other leg of the compass of course rests on

a suitable washer.

To the best of my recollection the further procedure was as follows.

A piece of steel rod about one-eighth inch in diameter was ground off

flat and mounted in a vice vertically, so as to cause its plane end to

form a small horizontal anvil. The centre (approximately) of the

diamond-cut circle of the glass was laid on this anvil so as to rest

evenly upon it, and the upper surface (i.e. that containing the cut)

was then struck smartly with a hammer, completely pulverising the

glass above the anvil. The hole was gradually extended in a similar

manner right up to the diamond cut, from which, of course, the glass

broke away.

A similar method has long been known to glaziers, differing from the

preceding in that a series of diamond cuts are run across the circle

parallel to two mutually perpendicular diameters. A smart tap on the

back of the scored disc will generally cause the fragments to tumble

out. I have never tried this myself, but I have seen it done.

Large discs may easily be cut from sheet glass by drawing a circular

diamond cut, and gradually breaking away the outer parts by the aid of

additional cuts and a pair of pliers or "shanks" (see Fig. 44).

§ 41. Operations depending on Grinding: Ground-in Joints.

The process will be perfectly understood by reference to a simple

case. Suppose it is desired to grind the end of a tube into the neck

of a bottle. If a stoppered bottle is available, the stopper must be

taken out and measured as to its diameter at the top and bottom.

Select a bit of tube as nearly as possible of the same diameter as the

stopper at its thickest part. Draw down the glass in the blow-pipe

flame rather by allowing it to sink than by pulling it out. After a

few trials no difficulty will be experienced in making its taper

nearly equal to that of the stopper, though there will in all

probability be several ridges and inequalities. When this stage is

reached anneal the work carefully and see that the glass is not too

thin. Afterwards use emery and water, and grind the stopper into the

bottle.

There are six special directions to be note

(1 )Turn the stopper through at least one revolution in each

direction.

(2) Lift it out often so as to give the fresh emery a chance of

getting into the joint.

(3) Rotate the bottle as well as the stopper in case there is any

irregularity in the force brought to bear, which might cause one side

of the neck to be more ground than another, or would cause the tube to

set rather to one side or the other.

(4) Use emery passing a 50 sieve, i.e. a sieve with fifty threads to

the inch run (see § 144) to begin with, and when the stopper nearly

fits, wash this thoroughly away, and finish with flour emery,

previously washed to get rid of particles of excessive size; the

process of washing will be fully discussed in the chapter on

glass-grinding, which see.

(5) Any degree of fineness of surface may be obtained by using graded

emery, as will be explained, but, in general, it is unnecessary to

attempt a finer surface than can be got with washed flour emery. A

superficial and imperfect polish may be given by grinding for a short

time with powdered pumice stone.

(6) If the proper taper is not attained by blowing, or if ridges are

left on the tapered part, the process may be both hastened and

improved by giving the taper a preliminary filing with a

three-cornered file and kerosene, just as one would proceed with iron

or brass. A little filing will often save a good deal of grinding and

make a better job.

If a bottle without a tapered neck is to be employed, it is as well to

do the preliminary grinding by means of a cone turned up from a bit of

cast iron. This is put in the lathe and pushed into the mouth of the

bottle, the latter being supported by the hands. Use about the same

surface speed as would be employed for turning cast iron. In this

case the emery is better used with kerosene.

If a cylindrical bit of cast iron about an inch in diameter is turned

down conically nearly to a point, it will save a good deal of trouble

in making separate cones. If it gets ground into rings, and it

becomes necessary to turn it up, use a diamond tool until the skin is

thoroughly removed; the embedded emery merely grinds the edge off any

ordinary steel tool.

For diamond tools see § 55.

§ 42. Use of the Lathe in Glass-working.

If it is necessary to remove a good deal of glass, time may be saved

by actually turning the glass in a lathe. According to the direction

given above for grinding a tube into the neck of a bottle, very little

glass need be removed if the drawing down is well done, so that for

this purpose turning is often unnecessary.

If the taper of the stopper be small and it is permissible to use a

thick tube, or if a solid stopper only has to be provided, or an old

stopper quickly altered to a new form, turning is very useful. The

glass may be "chucked" in any suitable manner, and run at a speed not

exceeding 10 feet per minute. Prepare a three-cornered file by

mercury-hardening and by grinding the end flat so as to form a cutting

angle of about 80°, and use a moderate amount of kerosene lubrication,

i.e. enough to keep the glass damp, but even this is not essential.

Use the file as an ordinary brass turning tool, and press much more

lightly than for metal turning. The glass will be found to scrape off

quite pleasantly.

By chucking glass tubes on wooden mandrells the ends may be nicely

turned in this manner ready for accurate closing by glass plates.

The process of grinding also is made much more rapid--at all events

in the earlier stages--by chucking either the stopper or the bottle

and holding the other member in the fingers, or in a wooden vice held

in the hands. The finishing touches are best given by hand.

I ought to say that I think a good deal of glass-grinding, as

practised in laboratories, might be advantageously replaced by glass

turning or filing and certainly will be by any one who will give these

methods a trial.

If one tube is to be ground into another, as in grinding a retort into

a receiver, the latter must be drawn down from a larger piece, few

beginners being able to widen a tube by the method explained with

sufficient ease and certainty. The other operations are similar to

the operations above described.

§ 43. Funnels often require to be ground to an angle of 60°. For

this purpose it is well to keep a cast-iron cone, tapering from

nothing up to four inches in diameter. This may be mounted on a

lathe, and will be found of great use for grinding out the inside of

funnels. Care must be taken to work the funnel backwards and

forwards, or it will tend to grind so as to form rings, which

interfere with filtering. A rough polish may be given on the lines

explained in the next section.

§ 44. A rough polish may be easily given to a surface which has been

finished by washed flour emery, in the following manner. Turn up a

disc of soft wood on the lathe, and run it at the highest wood-turning

speed. Rub into the periphery a paste of sifted powdered pumice stone

and water.

Any fairly smooth ground glass surface may be more or less polished by

holding it for a moment against the revolving disc. Exact means of

polishing will be described later on. Meanwhile this simple method

will be found both quick and convenient, and is often quite sufficient

where transparency, rather than figure, is required. I daresay a fine

polish may be got on the same lines, using putty powder or washed

rouge (not jewellers' rouge, which is too soft, but glass-polishers'

rouge) to follow the pumice powder, but I have not required to try

this.

§ 45. It is sometimes required to give to ground glass surfaces a

temporary transparency. This is to be done by using a film of oil of

the same refractive index as the glass. Cornu has employed a varnish

consisting of a mixture of turpentine and oil of cloves, but the

yellow-brown colour of the latter is often a disadvantage. It will be

found that a mixture of nut oil and oil of bitter almonds, or of

bromo-napthalene and acetone, can be made of only a faint yellow

colour; and by exact adjustment of the proportions will have the same

refractive index for any ray as crown glass (ordinary window glass).

Procure a sample of the glass and smash it up to small fragments in an

iron mortar. Sift out the fine dust and the larger pieces; bits

about as large as small beads--say one-sixteenth inch every way--do

very well. Boil the sifted glass with strong commercial hydrochloric

acid to remove iron, wash with distilled water and a few drops of

alcohol, dry on blotting paper in the sun or otherwise. Put the dry

glass into a bottle or beaker, and begin by adding almond oil (or

bromo-napthalene), then add nut oil (or acetone) till the glass

practically disappears when examined by sodium light, or light of any

other wave-length, as may be required.

The adjustment of the mixture is a matter of great delicacy, one drop

too much of either constituent, in, say, 50 cubic centimetres, makes

all the difference. The final adjustment is best accomplished by

having two mixtures of the oils, one just too rich in almond, the

other in nut oil; by adding one or other of these, the required

mixture is soon obtained.

It is to be noted

(1) That adjustment is only perfect for light of one wave-length.

(2) That adjustment is only perfect at one temperature.

On examining a bottle of rather larger fragments of glass immersed in

an adjusted mixture by ordinary daylight, a peculiarly beautiful play

of colours is seen.

Of course, if it is only desired to make ground glass fairly

transparent, these precautions are unnecessary, but it seemed better

to dispose of the matter once for all in this connection.

M. Cornu's object was to make a varnish which would prevent reflection

from the back of a photographic plate on to the film. I have had

occasion to require to do the same when using a scale made by cutting

lines through a film of black varnish on a slip of glass. This

succeeded perfectly by making the varnish out of Canada balsam stained

with a black aniline dye.

Mr. Russell, Government Astronomer of New South Wales, finds that the

"halation" of star photographs can be prevented by pouring over the

back of the plate a film of collodion suitably stained.

§ 46. Making Ground Glass.

This is easily done by rubbing the surface of polished glass with a

bit of cast iron and washed "flour of emery." Of course, if the

fineness of grain of the surface is of importance, appropriate sizes

of emery must be employed. The iron may be replaced by a bit of glass

cut with transverse grooves to allow the emery to distribute itself,

or even by a bit of glass without such grooves, provided it does not

measure more than one or two inches each way. If great speed is an

object rather than the fineness of the surface, use a bit of lead and

coarse emery, say any that will pass a sieve with fifty threads to the

inch.

It may perhaps be mentioned here that it is a pity to throw away emery

which has been used between glass and glass. In the chapter dealing

with fine optical work the use of emery of various grades of fineness

will be treated, and the finer grades can only be obtained (to my

knowledge) from emery which has been crushed in the process of glass

or metal grinding, especially the former. A large jam-pot covered

with a cardboard lid does well as a receptacle of washings.

§ 47. Glass-cutting.

This is an art about which more can be learned in five minutes by

watching it well practised than by pages of written description. My

advice to any one about to commence the practice of the art would be

to make friends with a glazier and see it done. What follows is

therefore on the supposition that this advice has been followed.

After some experience of cutters made of especially hardened steel, I

believe better work can generally be got out of a diamond, provided

the cost is not an objection. It is economy to pay a good price for a

good diamond. As is well known, the natural angle of the crystal

makes the best point, and a person buying a diamond should examine the

stone by the help of a lens, so as to see that this condition is

fulfilled. The natural angle is generally, if not always, bounded by

curved edges, which have a totally different appearance from the sharp

edges of a "splinter."

When a purchase is to be made, it is as well for the student to take a

bit of glass and a foot-rule with him, and to test the diamond before

it is taken away. When a good diamond has been procured, begin by

taking cuts on bits of clean window glass until the proper angle at

which to hold the tool is ascertained. Never try to cut over a

scratch, if you value your diamond, and never press hard on the glass;

a good cut is accompanied by an unmistakable ringing sound quite

different from the sound made when the diamond is only scratching.

Perhaps the most important advice that can be given is, Never lend the

diamond to anybody--under any circumstances.

The free use of a diamond is an art which the physicist will do well

to acquire, for quite a variety of apparatus may be made out of glass

strips, and the accuracy with which the glass breaks along a good cut

reduces such an operation as glass-box-making to a question of

accurate drawing.

§ 48. Cementing.

One of the matters which is generally confused by too great a

profusion of treatment is the art of cementing glass to other

substances.

The following methods will be found to work, subject to two

conditions:

(1) The glass must be clean;

(2) it must be hot enough to melt the cement.

For ordinary mending purposes when the glass does not require to be

placed in water (especially if hot) nothing is better than that kind

of glue which is generally called "diamond cement." This may be

easily made by dissolving the best procurable isinglass in a mixture

of 20 per cent water and 80 per cent glacial acetic acid--the exact

proportions are not of consequence.

First, the isinglass is to be tightly packed into a bottle with a wide

neck, then add the water, and let the isinglass soak it up.

Afterwards pour in the acetic acid, and keep the mixture near 100°C.

for an hour or two on the water bath--or rather in it. The total

volume of acetic acid and water should not be more than about half of

the volume of isinglass when the latter is pressed into the bottle as

tightly as possible.

The proper consistency of the cement may be ascertained by lifting a

drop out of the bottle and allowing it to cool on a sheet of glass.

In ten minutes it ought not to be more than slightly sticky, and the

mass in the bottle, after standing a few hours cold, should not be

sticky at all, and should yield, jelly-like, to the pressure of the

finger to only a slight degree. If the glue is too weak, more

isinglass may be added (without any preliminary soaking).

A person making the mixture for the first time almost always gets it

too weak. It is difficult to give exact proportions by weight, as

isinglass and gelatine (which may replace it) differ greatly in

quality. This cement is applied like glue, and will cement nearly

anything as well as glass. Of course, as much cement as possible must

be squeezed out of any joint where it is employed. The addition of

gums, as recommended in some books, is unnecessary.

Ordinary glue will serve perfectly for cementing glass to wood.

"Chipped glass" ware is, I understand, made by painting clean glass

with glue. As the glue dries and breaks by contraction, it chips off

the surface of the glass. I have never seen this done. In nearly all

cases where alcohol is not to be employed very strong joints may be

made by shellac. Orange shellac is stronger than the "bleached"

variety.

A sine qua non is that the glass be hot enough to melt the shellac.

The best way is to heat the glass surfaces and rub on the shellac from

a bit of flake; the glass should not be so hot as to discolour the

shellac appreciably, or its valuable properties will be partly

destroyed. Both glass surfaces being thus prepared, and the shellac

being quite fluid on both, they may be brought together and clamped

tightly together till cool. Shellac that has been overheated, or

dissolved in alcohol, or bleached, is of little use as compared with

the pale orange flaky product. Dark flakes have probably been

overheated during the preliminary refining.

For many purposes a cement is required capable of resisting carbon

bisulphide. This is easily made by adding a little treacle (say 20

per cent) to ordinary glue. Since the mixture of glue and treacle

does not keep, i.e. it cannot be satisfactorily melted up again after

once it has set, no more should be made up than will be wanted at the

time. If the glue be thick, glass boxes for carbon disulphide may be

easily put together, even though the edges of the glass strips are not

quite smooth, for, unlike most cements, this mixture remains tough,

and is fairly strong in itself.

I have found by experiment that most fixed and, to a less degree,

essential oils have little or no solvent action on shellac, and I

suspect that the same remark applies to the treacle-glue mixture, but

I have not tried. Turpenes act on shellac slightly, but mineral oils

apparently not at all. The tests on which these statements are based

were continued for about two years, during which time kerosene and

mineral oils had no observable effect on shellac--fastened

galvanometer mirrors.

§ 49. Fusing Electrodes into Glass.

This art has greatly improved since the introduction of the

incandescent lamp; however, up to the present, platinum seems to

remain the only substance capable of giving a certainly air-tight

result. I have not tried the aluminium-alumina method.

Many years ago it was the fashion to surround the platinum wire with a

drop of white enamel glass in order to cause better adhesion between

it and the ordinary glass. [Footnote: Hittorf and Geissler (Pogg.

Ann. 1864, § 35; English translation, Phys. Soc. London, p. 138)

found that it was impossible to make air-tight joints between platinum

and hard potash glass, but that soft lead glass could be used with

success as a cement.] However, in the case of flint glass, if one may

judge from incandescent lamps, this is not essential--a fact which

entirely coincides with my own experience.

On the other hand, when sealing electrodes into German glass I have

often used a drop of enamel with perfect results, though this is not

always done in Germany. In all cases, however, in which electrodes

have to be sealed in--especially when they are liable to heat--I

recommend flint glass, and in this have the support of Mr. Rain (The

Incandescent Lamp and its Manufacture, p. 131). The exact details

for the preparation of eudiometer tubes are given by Faraday (Chemical

Manipulation, § 1200).

In view of what has preceded, however, I will content myself with the

following notes. Make the hole through which the wire is to protrude

only slightly larger than the wire itself, and be sure that the latter

is clean. Allow the glass to cool sufficiently not to stick to the

wire when the latter is pushed in. Be sure that, on heating, the

glass does not get reduced, and that it flows up to the wire all

round; pull and push the wire a little with a pair of pincers, to

ensure this.

It is not a bad plan to get the glass exceedingly fluid round the

wire--even if the lump has to be blown out a little afterwards--as it

cools. The seal should finally be well annealed in asbestos, but

first by gradually moving it into the hot air in front of the flame.

It was observed by Professor J. J. Thomson and the author some years

ago (Proc. Roy. Soc. 40. 331. 1886) that when very violent

discharges are taken through lightly sealed-in electrodes in

lead-glass tubes--say from a large battery of Leyden jars--gas

appears to be carried into the tube over and above that naturally

given off by the platinum, and this without there being any apparent

want of perfection in the seal. This observation has since been

confirmed by others. Consequently in experiments on violent

discharges in vacuo where certainty is required as to the exclusion of

air, the seals should be protected by a guard tube or cap containing

mercury; this must, of course, be put in hot and clean, on hot and

clean glass, and in special cases should be boiled in situ.

A well-known German physicist (Warburg, I think) recommends putting

the seals under water, but I cannot think that this is a good plan,

for if air can get in, why not water? which has its surface tension

in its favour. The same reasoning prevents my recommending a layer of

sulphuric acid above the mercury-a method used for securing

air-tightness in "mercury joints" by Mr. Gimingham, Proc. R. S.

1874.

Further protection may be attained for many purposes by coating the

platinum wire with a sheath of glass, say half an inch long, fused to

the platinum wire to a depth of one-twentieth of an inch all round.

In some cases the electrodes must be expected to get very hot, for

instance, when it is desired to platinise mirrors by the device of

Professor Wright of Yale. In this and similar cases I have met with

great success by using "barometer" tubes of about one-twelfth of an

inch bore, and with walls, say, one-tenth of an inch thick.

[Footnote: "Barometer" tube is merely very thick-walled glass tubing,

and makes particularly bad barometers, which are sold as weather

glasses.]

This tube is drawn down to a long point--say an inch long by

one-eighth of an inch external diameter, and the wire is fused in for

a length, say, of three-quarters of an inch, but only in the narrow

drawn--down part of the tube. At different times I have tried four

such seals, and though the electrodes were red hot for hours, I have

never had an accident--of course they were well annealed.

Fig. 37.

For directions as to the making of high vacuum tubes, see the section

dealing with that matter.

§ 50. As economy of platinum is often of importance, the following

little art will save money and trouble. Platinum is easily caused to

join most firmly to copper--with which, I presume, it alloys--by the

following method. Hold the platinum wire against the copper wire, end

to end, at the tip of the reducing flame of a typical blowpipe--or

anywhere--preferably in the "reducing" part of the oxygas flame; in

a moment the metals will fuse together at the point of contact, when

they may be withdrawn.

Such a joint is very strong and wholly satisfactory, much better than

a soldered joint. If the work is not carried out successfully so that

a considerable drop of copper-platinum alloy accumulates, cut it off

and start again. The essence of success is speed, so that the copper

does not get "burned." If any considerable quantity of alloy is formed

it dissolves the copper, and weakens it, so that we have first the

platinum wire, then a bead of alloy, and then a copper wire fused into

the bead, but so thin just outside the latter that the joint has no

mechanical strength.

§ 51. The Art of making Air-light Joints.

Lamp-manufacturers and others have long since learned that when glass

is in question not only are fused joints made as easily as others, but

that they afford the only reliable form of joint. An experimenter who

uses flint glass, has a little experience, an oxygas blow-pipe and a

blowing apparatus, will prefer to make his joints in this way, simply

from the ease with which it may be done. When it comes to making a

tight joint between glass and other substances the problem is by no

means so easy. Thus Mr. Griffiths (Phil. Trans. 1893, p. 380)

failed to make air-tight joints by cementing glass into steel tubes,

using hard shellac, and the tubes fitting closely. These joints were

satisfactory at first, but did not last; the length of the joint is

not stated. The difficulty was finally got over by soldering very

narrow platinum tubes into the steel, and fusing the former into the

glass.

Mr. Griffiths has since used an alloy with success as a cement, but I

cannot discover what it is made from. Many years ago Professor Hittorf

prepared good high vacuum tubes by plugging the ends of glass tubes

with sealing wax merely, though in all cases the spaces to be filled

with wax were long and narrow (Hittorf, Pogg. Ann. 1869, § 5,

English translation, Phys. Soc. p. 113). Again, Regnault

habitually used brass ferules, and cemented glass into them by means

of his mastic, which can still be procured at a low rate from his

instrument-makers (Golan, Paris). Lenard also, in his investigations

on Cathode Rays (Wied. Ann, vol. li. p. 224), made use of sealing

wax covered with marine glue.

Surely in face of these facts we must admit that cement joints can be

made with fair success. I do not know the composition of M.

Regnault's mastic, but Faraday (Manipulations, § 1123) gives the

following receipt for a cement for joining ferules to retorts, etc:

Resin 5 parts.

Beeswax 1 part.

Red ochre or Venetian red,

finely powdered and sifted 1 part.

I believe this to be substantially the same as Regnault's mastic,

though I have never analysed the latter.

For chemical work the possibility of evolution of gas from such a

cement must be taken into account, and I should certainly not trust it

for this reason in vacuum tube work, where the purity of the confined

gas could come in question. Otherwise it is an excellent cement, and

does not in my experience tend to crack away from glass to the same

extent as paraffin or pure shellac.

This cracking away from glass, by the way, is probably an effect of

difference in rate of expansion between the glass and cement which

probably always exists, and, if the cement be not sufficiently

viscous, must, beyond certain temperature limits, either produce

cracks or cause separation. Professor Wright of Yale has used a hard

mineral pitch as a cement in vacuum work with success.

My attention has been directed to a fusible metal cement containing

mercury, and made according to the following receipt, given by Mr. S.

G. Rawson, Journal of the Society of Chemical Industry, vol. ix.

(1890), P. 150:-

Bismuth 40 per cent

Lead 25 per cent

Tin 10 per cent

Cadmium 10 per cent

Mercury 15 per cent

This is practically one form of Rose's fusible metal with 15 per cent

mercury added. It takes nearly an hour to set completely, and the

apparatus must be clean and warm before it is applied.

As the result of several trials by myself and friends, I am afraid I

must dissent from the claim of the author that such a cement will make

a really air-tight joint between glass tubes. Indeed, the appearance

of the surface as viewed through the glass is not such as to give any

confidence, no matter what care may have been exercised in performing

all the operations and cleaning the glass; besides which the cement

is rigid when cold, and the expansion difficulty comes in.

On the other hand, if extreme air-tightness is not an object, the

cement is strong and easily applied, and has many uses. I have an

idea that if the joints were covered with a layer of soft wax, the

result would be satisfactory in so far as air-tightness is concerned.

This anticipation has since been verified.

In many cases one can resort to the device already mentioned of

enclosing a rubber or tape-wrapped joint between two tubes in a bath

of mercury, but in this case the glass must be clean and hot and the

mercury also warm, dry, and pure when the joint is put together,

otherwise an appreciable air film is left against the glass, and this

may creep into the joint.

Perhaps the easiest way of making such a joint is to use an outer tube

of thin clean glass, and bore a narrow hole into it from one side to

admit the mercury; if the mercury is to be heated in vacuo, it is

better to seal on a side joint. It is always better, if possible, to

boil the mercury in situ, which involves making the wrapping of

asbestos, but, after all, we come back to the position I began by

taking up, viz. that the easiest and most reliable method is by

fusion of the glass--all the rest are unsuitable for work of real

precision.

I should be ungrateful, however, were I not to devote a few lines to

the great convenience and merit of so-called "centering cement." This

substance has two or three very valuable properties. It is very tough

and strong in itself, and it remains plastic on cooling for some time

before it really sets. If for any reason a small tube has to be

cemented into a larger one, which is a good deal larger, so that an

appreciable mass of cement is necessary, and particularly if the joint

requires to have great mechanical strength, this cement is invaluable.

I have even used a plug of it instead of a cork for making the joint

between a gas delivery tube and a calcium chloride tower. (Why are

these affairs made with such abominable tubulures?)

The joint in question has never allowed the tube to sag though it

projects horizontally to a distance of 6 inches, and has had to

withstand nearly two years of Sydney temperature. The cement consists

of a mixture of shellac and 10 per cent of oil of cassia.

The shellac is first melted in an iron ladle, and the oil of cassia

quickly added and stirred in, to an extent of about 10 per cent, but

the exact proportions are not of importance. Great care must be taken

not to overheat the shellac.

APPENDIX TO CHAPTER I

ON THE PREPARATION OF VACUUM TUBES FOR THE PRODUCTION OF PROFESSOR

ROENTGEN'S RADIATION

[Footnote: Written in May 1896.]

WHEN Professor Roentgen's discovery was first announced at the end of

1895 much difficulty was experienced in obtaining radiation of the

requisite intensity for the repetition of his experiments. The

following notes on the production of vacuum tubes of the required

quality may therefore be of use to those who desire to prepare their

own apparatus. It appears that flint glass is much more opaque to

Roentgen's radiation than soda glass, and consequently the vacuum

tubes require to be prepared from the latter material.

Fig. 39.

A form of vacuum tube which has proved very successful in the

author's hands is sketched in Fig. 38. It is most easily constructed

as follows. A bit of tubing about 2 centimetres diameter, 15

centimetres long, and 1.5 millimetre wall thickness, is drawn down to

a point. The larger bulb, about 5 centimetres in diameter, is blown

at one end of this tube. The thinner the bulb the better, provided

that it does not collapse under atmospheric pressure. A very good

idea of a proper thickness may be obtained from the statement that

about 4 centimetres length of the tubing should be blown out to form

the bulb. This would give a bulb of about the thickness of an

ordinary fractionating bulb. Before going any further it is as well

to test the bulb by tapping on the table and by exhausting it by means

of an ordinary water-velocity pump.

The side tube is next prepared out of narrower tubing, and is provided

with a smaller bulb, a blowing-out tube, and a terminal, to be made as

will be described. This side tube is next fused on to the main tube,

special care being taken about the annealing, and the cathode terminal

is then sealed into the main tube. After using clean glass it is in

general only necessary to rinse the tube out with clean alcohol, after

which it may be dried and exhausted.

The success of the operation will depend primarily on the attention

given to the preparation and sealing-in of the electrode facing the

large bulb.

Preparation of Terminals. Some platinum wire of about No. 26

B.W.G--the exact size is unimportant--must be provided, also some

sheet aluminium about 1 millimetre thick, some white enamel cement

glass, and a "cane" of flint-glass tube of a few millimetres bore.

The electrodes are prepared by cutting discs of aluminium of from 1 to

1.5 centimetres diameter. The discs of aluminium are bored in the

centre, so as to admit the "stems" which are made of aluminium wire

of about 1 millimetre diameter. The stems are then riveted into the

discs. The "stems" are about I centimetre long, and are drilled to a

depth of about 3 millimetres, the drill used being about double the

diameter of the platinum wire to be used for making the connections.

The faces of the electrodes--i.e. the free surfaces of the aluminium

discs--are then hammered flat and brought to a burnished surface by

being placed on a bit of highly polished steel and struck by a "set"

provided with a hole to allow of the "stem" escaping damage. The

operation will be obvious after a reference to Figs. 39 and 40; it

is referred to again on page 96.

The platinum wires may be most conveniently attached by melting one

end of the piece of platinum wire in the oxygas blow-pipe till it

forms a bead just large enough to pass into the hole drilled up the

stem of the electrode. The junction between the stein and the

platinum wire is then made permanent by squeezing the aluminium down

upon the platinum wire with the help of a pair of pliers. It is also

possible to fuse the aluminium round the platinum, but as I have had

several breakages of such joints, I prefer the mechanical connection

described.

Fig. 39. Sets for striking aluminium electrodes

Fig. 40.

i. Aluminium electrode.

ii. Aluminium electrode connected to platinum wire.

iii. Aluminium electrode connected to platinum wire and protected by

glass.

iv. Detail of fastening platinum wire.

The stem and platinum wire may now be protected by covering them with

a little flint glass. For this purpose the flint-glass tube is pulled

down till it will just slip over the stem and wire, and is cut off so

as to leave about half a centimetre of platinum wire projecting. The

flint-glass tube is then fused down upon the platinum wire, care being

taken to avoid the presence of air bubbles. At the close of the

operation a single drop of white enamel glass is fused round the

platinum wire at a high temperature, so as to make a good joint with

the protecting flint-glass tube.

The negative electrode being nearly as large as the main tube, it must

be introduced before the latter is drawn down for sealing. After

drawing down the main tube in the usual manner, taking care not to

make it less than a millimetre in wall-thickness, it is cut off so as

to leave a hole not quite big enough for the enamel drop to pass

through. By heating and opening, the aperture is got just large

enough to allow the enamel drop to pass into it, and when this is the

case the joint is sealed, pulled, and blown out until the electrode

occupies the right position--viz. in the centre of the tube and with

its face normal to the axis of the tube.

The glass walls near the negative electrode must not be less than a

millimetre thick, and may be rather more with advantage, the glass

must be even, and the joint between the flint glass and the soda

glass, or between the wire and the soda glass, must be wholly through

the enamel. The "seal" must be well annealed. It will be found that

the sealing-in process is much easier when the stem of the electrode

is short and when the glass coating is not too heavy. Half a

millimetre of glass thickness round the stein is quite sufficient.

The diagram, of the tube shows that the main tube has been expanded

round the edges of the cathode. This is to reduce the heating

consequent on the projection of cathode rays from the edges of the

disc against the glass tube.

The anode is inserted into its bulb in a quite similar manner. If

desired it may be made considerably smaller, and does not need the

careful adjustment requisite in sealing-in the cathode, nor does the

glass near the entry wire require to be so thick.

More intense effects are often got by making the cathode slightly

concave, but in this case the risk of melting the thin glass is

considerably increased. No doubt, Bohemian glass might be used

throughout instead of soft soda glass, and this would not melt so

easily; the difficulties of manipulating the glass are, however, more

pronounced.

It will be shown directly that the best Roentgen effects are got with

a high vacuum, and it is for this reason that the glass near the

cathode seal requires to be strong. The potential right up to the

cathode is strongly positive inside the tube, and this causes the

glass to be exposed to a strong electric stress in the neighbourhood

of the seal.

Although the glass-blowing involved in the making of a so-called focus

tube is rather more difficult than in the case just described, there

is no reason why such a difficulty should not be overcome; I will

therefore explain how a focus tube may be made.

Fig. 41.

A bulb about 3 inches in diameter is blown from a bit of tube of a

little more than 1 inch diameter. Unless the walls of the tube are

about one-eighth of an inch in thickness, this will involve a

preliminary thickening up of the glass. This is not difficult if care

be taken to avoid making the glass too hot. The larger gas jet

described in connection with the soda-glass-blowing table must be

employed. In blowing a bulb of this size it must not be forgotten

that draughts exercise a very injurious influence by causing the glass

to cool unequally; this leads to bulbs of irregular shape.

In the method of construction shown in Fig. 41, the anode is put in

first. This anode simply consists of a square bit of platinum or

platinum-iridium foil, measuring about 0.75 inch by 1 inch, and

riveted on to a bent aluminium wire stem.

As soon as the anode is fused in, and while the glass is still hot,

the side tube is put on. The whole of the anode end is then carefully

annealed. When the annealing is finished the side tube is bent as

shown to serve as a handle when the time comes to mount the cathode.

Before placing the cathode in position, and while the main tube is

still wide open, the anode is adjusted by means of a tool thrust in

through this open end. This is necessary in view of the fact that the

platinum foil is occasionally bent during the operation of forcing the

anode into the bulb.

The cathode is a portion of a spherical surface of polished aluminium,

a mode of preparing which will be given directly. The cathode having

been placed inside the bulb, the wide glass tube is carefully drawn

down and cut off at such a point that when the cathode is in position

its centre of curvature will lie slightly in front of the anode plate.

For instance, if the radius of curvature of the cathode be 1.5 inches,

the centre of curvature may lie something like an eighth of an inch or

less in front of the anode.

The cathode as shown in Fig. 41 is rather smaller than is

advantageous. To make it much larger than is shown, however, the

opening into the bulb would require to be considerably widened, and

though this is not really a difficult operation, still it requires

more practice than my readers are likely to have had. The difficulty

is not so much in widening out the entry as in closing it down again

neatly.

Now as to making the anode. A disc of aluminium is cut from a sheet

which must not be too thick--one twenty-fifth of an inch is quite

thick enough. This disc is bored at the centre to allow of the stem

being riveted in position. The disc is then annealed in the Bunsen

flame and the stem riveted on.

The curvature is best got by striking between steel dies (see Figs.

39 and 40). Two bits of tool steel are softened and turned on the

lathe, one convex and the other concave. The concave die has a small

hole drilled up the centre to admit the stem. The desired radius of

curvature is easily attained by cutting out templates from sheet zinc

and using them to gauge the turning. The two dies are slightly ground

together on the lathe with emery and oil and are then polished, or

rather the convex die is polished--the other one does not matter.

The polishing is most easily done by using graded emery and oil and

polishing with a rag. The method of grading emery will be described

in the chapter on glass-grinding.

The aluminium disc is now struck between the dies by means of a

hammer. If the radius of curvature is anything more than one inch and

the disc not more than one inch in diameter the cathode can be struck

at once from the flat as described. For very deep curves no doubt it

will be better to make an intermediate pair of dies and to re-anneal

the aluminium after the first striking.

When the tube is successfully prepared so far as the glassblowing goes

it may be rinsed with strong pure alcohol both inside and out, and

dried. The straight part of the side tube is then constricted ready

for fusing off and the whole affair is placed on the vacuum pump.

In spite of the great improvements made during recent years in the

construction of so-called Geissler vacuum pumps--i.e. pumps in which

a Torricellian vacuum is continually reproduced--I am of opinion that

Sprengel pumps are, on the whole, more convenient for exhausting

Crooke's tubes. A full discussion of the subject of vacuum pumps will

be found in a work by Mr. G. S. Ram (The Incandescent Lamp and its

Manufacture), published by the Electrician Publishing Company, and it

is not my intention to deal with the matter here; the simplest kind of

Sprengel pump will be found quite adequate for our purpose, provided

that it is well made.

Fig. 42 is intended to represent a modification of a pump based on

the model manufactured by Hicks of Hatton Garden, and arranged to suit

the amateur glass-blower. The only point of importance is the

construction of the head of the fall tube, of which a separate and

enlarged diagram is given. The fall tubes may have an internal

diameter up to 2 mm. (two millimetres) and an effective length of 120

cm.

Free use is made of rubber tube connections in the part of the pump

exposed to the passage of mercury. The rubber employed should be

black and of the highest quality, having the walls strengthened by a

layer of canvas. If such tube cannot be easily obtained, a very good

substitute may be made by placing a bit of ordinary black tube inside

another and rather larger bit and binding the outer tube with tape or

ribbon. In any case the tubing which comes in contact with the

mercury should be boiled in strong caustic potash or soda solution for

at least ten minutes to get rid of free sulphur, which fouls the

mercury directly it comes in contact with it. The tubing is well

washed, rinsed with alcohol, and carefully dried.

Fig. 42.

The diagram represents what is practically a system of three Sprengel

pumps, though they are all fed from the same mercury reservoir and run

down into the same mercury receiver. It is much easier to make three

pumps, each with separate pinch cocks to regulate the mercury supply,

than it is to make three jets, each delivering exactly the proper

stream of mercury to three fall tubes.

Sprengel pumps only work at their highest efficiency when the mercury

supply is carefully regulated to suit the peculiarities of each fall

tube, and this is quite easily done in the model figured. Since on

starting the pump the rubber connections have to stand a considerable

pressure, the ends of the tubes must be somewhat corrugated to enable

the rubber to be firmly wired on to them. The best binding wire is the

purest Swedish iron wire, previously annealed in a Bunsen gas flame.

The wire must never be twisted down on the bare rubber, but must

always be separated from it by a tape binding. By taking this

precaution the wire maybe twisted very much more tightly than is

otherwise possible without cutting the rubber.

The only difficulty in making such a pump as is described lies in the

bending of the heads of the fall tubes. This bending must be done

with perfect regularity and neatness, otherwise the drops of mercury

will not break regularly, or will break just inside the top of the

fall tube, and so obstruct its entrance that at high vacua no air can

get into the tube at all.

The connections at the head of the fall tubes must also be well put on

and the joints blown out so that the mercury in dropping over the head

is not interfered with by the upper surface of the tube. However, a

glance at the enlarged diagram will show what is to be aimed at better

than any amount of description. In preparing the fall tubes it is

generally necessary to join at least two "canes" together. The joint

must be arranged to occur either in the tube leading the mercury to

the head of the fall, or in that part of the fall tube which remains

full of mercury when the highest vacuum is attained. On no account

must the joint be made at the fall itself (at least not by an

amateur), nor in that part of the fall tube where the mercury falls

freely, particularly at its lower end, where the drops fall on the

head of the column of mercury.

When a high vacuum is attained the efficacy of the pump depends

chiefly on the way in which the drops fall on the head of the column.

If the fall is too long the drops are apt to break up and allow the

small bubble of air to escape up the tube, also any irregularity or

dirt in the tube at this point makes it more easy for the bubbles of

air to escape to the surface of the mercury.

Any pump in which the supply of mercury to the fall tube can be

regulated nicely will pump well until the lowest available pressures

are being attained; a good pump will then continue to hold the air

bubbles, while a bad one will allow them to slip back [Footnote: For

special methods of avoiding this difficulty see Mr. Ram's book.] ...

Though three fall tubes are recommended, it must not be supposed that

the pump will produce a Crooke's vacuum three times more rapidly than

one fall tube. Until the mercury commences to hammer in the pump the

three tubes will pump approximately three times faster than one tube,

but as soon as the major portion of the air collected begins to come

from the layer condensed on the glass surface of the tube to be

exhausted and from the electrodes, the rate at which exhaustion will

go on no longer depends entirely on the pump.

In order that bubbles of air may not slip back up the fall tube it is

generally desirable to allow the mercury to fall pretty briskly, and

in this case the capacity of the pump to take air is generally far in

excess of the air supply. One advantage of having more than one fall

tube is that it often happens that a fall tube gets soiled during the

process of exhaustion and no longer works up to its best performance.

Out of three fall tubes, however, one is pretty sure to be working

well, and as soon as the mercury begins to hammer in the tubes the

supply may be shut off from the two falls which are working least

satisfactorily.

Thus we are enabled to pump rapidly till a high degree of exhaustion

is attained, having practically three pumps instead of one, whereas

when the final stages are reached, and three pumps are only a drawback

in that they increase the mercury flow, the apparatus is capable of

instant modification to meet the new conditions.

The thistle funnels at the head of the fall tubes are made simply by

blowing bulbs and then blowing the heads of the bulbs into wider ones,

and finally blowing the heads of the wider bulbs off by vigorous

blowing. The stoppers are ground in on the lathe before the tubes are

attached to the fall tubes. The stoppers require to be at least half

an inch long where they fit the necks, and must be really well ground

in. The stoppers must first be turned up nicely and the necks ground

out by a copper or iron cone and emery. The stoppers are rotated on a

lathe at quite a slow speed, say 30 or 40 feet per minute, and the

necks are held against them, as described in the section dealing with

this art. The stoppers must in this case be finished with "two

seconds" emery, and lastly with pumice dust and water (see chapter on

glass-grinding).

Unless the stoppers fit exceedingly well trouble will arise from the

mercury (which is poured into the thistle heads to form a seal) being

forced downwards into the pump by atmospheric pressure.

The joints between the three fall tubes and the single exhaust main

are easily made when the tubes are finally mounted, the hooked nozzle

of the oxygas blow-pipe being expressly made for such work.

It is, on the whole, advisable to make the pump of flint glass, or at

all events the air-trap tube and the fall tubes. A brush flame from

the larger gas tube of the single blowpipe table is most suitable for

the work of bending the tubes. The jointing of the long, narrow bore

fall tubes is best accomplished by the oxygas flame, for in this way

the minimum of irregularity is produced; the blowing tubes will of

course be required for the job, and the narrow tubes must be well

cleaned to begin with.

The air trap is an important though simple part of the pump. Its

shoulder or fall should stand rather higher than the shoulders of the

fall tubes, so that the mercury may run in a thin stream through a

good Torricellian vacuum before it passes down to the fall tubes.

This is easily attained by regulating the main mercury supply at the

pinch cock situated between the tube from the upper reservoir and the

air-trap tube, the other cocks being almost wide open.

It might be thought that the mercury would tend to pick up air in

passing through the rubber connections to the fall tubes, but I have

not found this to be the case in practice. There is, of course, no

difficulty in eliminating the rubber connections between the fall

tubes and the mercury supply from the air trap, but it impresses a

greater rigidity on the structure and, as I say, is not in general

necessary. It must not be forgotten that the mercury always exercises

considerable pressure on the rubber joints, and so there is little

tendency for gas to come out of the rubber.

The thistle funnels at the head of the fall tubes provide a simple and

excellent means of cleaning the fall tubes. For this purpose some

"pure" sulphuric acid which has been boiled with pure ammonium

sulphate is placed in each thistle funnel, and when the fall tube is

dirty the connection to the mercury supply is cut off at the pinch

cock so as to leave the tube between this entry and the head of the

fall tube quite full of mercury, and the sulphuric acid is allowed to

run down the fall tube by raising the stopper. The fall tube should

be allowed to stand full of acid for an hour or so, after which it

will be found to be fairly clean.

Of course the mercury reservoir thus obtains a layer of acid above the

mercury, and as it is better not to run the risk of any acid getting

into the pump except in the fall tubes, the reservoir is best emptied

from the bottom, by a syphon, if a suitable vessel cannot be procured,

so that clean mercury only is withdrawn.

The phosphorus pentoxide tube is best made as shown simply from a bit

of wide tube, with two side connections fused to the rest of the pump.

It is no more trouble to cut the tube and fuse it up again when the

drying material is renewed than to adjust the drying tube to two fixed

stoppers, which is the alternative. The practice here recommended is

rendered possible only by the oxygas blow-pipe with hooked nozzle.

The connection between the pump and tube to be exhausted is made

simply by a short bit of rubber tube immersed in mercury.

The phosphorus pentoxide should be pure, or rather free from

phosphorus and lower oxides; unless this be the case, the vapour

arising from it is apt to soil the mercury in the pump. The

phosphorus pentoxide is purified by distilling with oxygen over

red-hot platinum black; if this cannot be done, the pentoxide should

at least be strongly heated in a tube, in a current of dry air or

oxygen, before it is placed in the drying tube.

The mercury used for the pump must be scrupulously clean. It does

not, however, require to have been distilled in vacuo. It is

sufficient to purify it by allowing it to fall in a fine spray into a

large or rather tall jar of 25 per cent nitric acid and 75 per cent

water. The mercury is then to be washed and dried by heating to, say,

110° C. in a porcelain dish.

Exhausting a Roentgen Tube.

With a pump such as has been described there is seldom any advantage

in fusing an extra connection to the vacuum tube so as to allow of a

preliminary exhaustion by means of a water pump. About half an hour's

pumping may possibly be saved by making use of a water pump.

The tube to be exhausted is washed and dried by careful heating over a

Bunsen burner and by the passage of a current of air. The exhausting

tube is then drawn down preparatory to sealing off, and the apparatus

placed upon the pump. It is best held in position by a wooden clamp

supported by a long retort stand.

Exhaustion may proceed till the mercury in the fall tubes commences to

hammer. At this point the tube must be carefully heated by a Bunsen

flame, the temperature being brought up to, say, 400° C. The heating

may be continued intermittently till little or no effect due to the

heating is discernible at the pump. When this stage is reached, or

even before, the electrodes may be connected up to the coil and a

discharge sent through the tube.

Care must be taken to stop the discharge as soon as a purple glow

begins to appear, because when this happens, the resistance of the

tube is very low, the electrodes get very hot, and may easily get

damaged by a powerful discharge, and the platinum of the anode (if a

focus tube is in question) begins to be distilled on to the glass.

The heating and sparking are to be continued till the resistance of

the tube sharply increases. This is tested by always having a spark

gap, conveniently formed by the coil terminals, in parallel with the

tube. If the terminals are points, it is convenient to set them at

about one quarter of an inch distance apart.

As soon as sparks begin to pass between the terminals of the spark gap

it becomes necessary to watch the process of exhaustion very

carefully. In the first place, stop the pump, but let the coil run,

and note whether the sparks continue to flow over the terminals. If

the glass and electrodes are getting gas free, the discharge will

continue to pass by the spark gap, but if gas is still being freely

given off, then in perhaps three minutes the discharge will return to

the tube, and pumping must be recommenced. The Roentgen effect only

begins to appear when the tube has got to so high a state of

exhaustion that the resistance increases rapidly.

By pumping and sparking, the resistance of the tube may be gradually

raised till the spark would rather jump over 2 inches of air than go

through the tube. When this state is attained the Roentgen effect as

tested by a screen of calcium tungstate should be very brilliant. No

conclusion as to the equivalent resistance of the tube can be arrived

at so long as the discharge is kept going continually. When the spark

would rather go over an inch of air in the spark gap than through the

tube the pumping and sparking may be interrupted and the tube allowed

to rest for, say, five minutes. It will generally be found that the

equivalent resistance of the tube will be largely increased by this

period of quiescence. It may even be found that the spark will now

prefer to pass an air gap 3 inches long.

In any case the sparking should now be continued, the pump being at

rest, and the variations of tube resistance watched by adjusting the

spark gap. If the resistance falls below an equivalent of 2 inches of

air in the gap the pump must be brought into action again and

continued until the resistance as thus estimated remains fairly

constant for, say, ten minutes. When this occurs the narrow neck of

the exhaust tube may be strongly heated till the blow-pipe flame

begins to show traces of sodium light. The flame must then be

withdrawn and the discharge again tested. This is necessary because

it occasionally happens that gas is given off during the heating of

the neck to the neighbourhood of its fusion temperature.

If all is right the neck may now be fused entirely off and the tube is

finished. Tubes of the focus pattern with large platinum anodes are

in general (in my experience) much more difficult to exhaust than

tubes of the kind first described. This is possibly to be attributed

mainly to the gas given off by the platinum, but is also, no doubt,

due to the tubes being much larger and exposing a larger glass

surface. The type of tube described first generally takes about two

hours to exhaust by a pump made as explained, while a "focus" tube has

taken as long as nine hours, eight of which have been consumed after

the tube was exhausted to the hammering point.

The pressure at which the maximum heating of the anode by the cathode

rays occurs is a good deal higher than that at which the maximum

Roentgen effect is produced. There is little doubt that the Roentgen

radiation changes in nature to some extent as the vacuum improves

either as a primary or secondary effect. It is therefore of some

importance to test the tube for the purpose for which it is to be used

during the actual exhaustion. It has been stated, for instance, that

the relative penetrability of bone and flesh to Roentgen radiation

attains a maximum difference at a certain pressure; this is very

likely the case. Whether this effect is a direct function of the

density of the gas in the tube, or whether it is dependent on the

voltage or time integral of the current during the discharge, are

questions which still await a solution.

The preparation of calcium tungstate for fluorescent screens is very

simple.

Commercial sodium tungstate is fused with dried calcium chloride in

the proportion of three parts of the former to two parts of the

latter, both constituents being in fine powder and well mixed

together. The fusion is conducted in a Fletcher's crucible furnace in

a clay crucible. The temperature is raised as rapidly as possible to

the highest point which the furnace will attain--i.e. a pure white

heat. At this temperature the mixture of salts becomes partly fluid,

or at least pasty, and the temperature may be kept at its highest

point for, say, a quarter of an hour. At the end of this time the

mass is poured and scraped on to a brick, and when cold is broken up

and boiled with a large excess of water to dissolve out all soluble

matter. The insoluble part, which consists of a gray shining powder,

is washed several times with hot water, and is finally dried on

filter paper in a water oven.

In order to prepare a screen the powder is ground slightly with very

dilute shellac varnish, and is then floated over a glass plate so as

to get an even covering. Unless the covering be very even the screen

is useless, and no pains should be spared to secure evenness. It is

not exactly easy to get a regular coat of the fluorescent material,

but it may be done with a little care.

CHAPTER II

GLASS-GRINDING AND OPTICIANS' WORK

§ 52. As no instructions of any practical value in this art have, so

far as I know, appeared in any book in English, though a great deal of

valuable information has been given in the English Mechanic and

elsewhere, I shall deal with the matter sufficiently fully for all

practical purposes. On the other hand, I do not propose to treat of

all the methods which have been proposed, but only those requisite for

the production of the results claimed. The student is requested to

read through the chapter before commencing any particular operation.

§ 53. The simplest way will be to describe the process of manufacture

of some standard optical appliance, from which a general idea of the

nature of the operations will be obtained. After this preliminary

account special methods may be considered in detail. I will begin

with an account of the construction of an achromatic object glass for

a telescope, not because a student in a physical laboratory will often

require to make one, but because it illustrates the usual processes

very well; and requires to be well and accurately made.

A knowledge of the ordinary principles of optics on the part of the

reader is assumed, for there are plenty of books on the theory of

lenses, and, in any case, it is my intention to treat of the art

rather than of the science of the subject. By far the best short

statement of the principles involved which I have seen is Lord

Rayleigh's article on Optics in the Encyclopaedia Britannica, and this

is amply sufficient.

The first question that crops up is, of course, the subject of the

choice of glass. It is obvious that the glass must be uniform in

refractive index throughout, and that it must be free from air bubbles

or bits of opaque matter. [Footnote: The complete testing of glass

for uniformity of refractive index can only be arrived at by grinding

and polishing a sufficient portion of the surfaces to enable an

examination to be made of every part. In the case of a small disc it

is sufficient to polish two or three facets on the edge, and to

examine the glass in a field of uniform illumination through the

windows thus formed. Very slight irregularities will cause a "mirage"

easily recognised.]

The simplest procedure is to obtain glass of the desired quality from

Messrs. Chance of Birmingham, according to the following abbreviated

list of names and refractive indices, which may be relied upon:-

Density. Refractive Index.

C D F G

Hard crown

2.85 1.5146 1.5172 1.5232 1.5280

Soft crown

2.55 1.5119 1.5146 1.5210 1.5263

Light flint

3.21 1.5700 1.5740 1.5839 1.5922

Dense flint

3.66 1 6175 1.6224 1.6348 1.6453

Extra dense flint

3.85 1.6450 1.6504 1.6643 1.6761

Double extra dense flint

4.45 1.7036 1.7103 1.7273 ...

The above glasses may be had in sheets from 0.25 to 1 inch thick, and

6 to 12 inches square, at a cost of, say, 7s. 6d. per pound.

Discs can also be obtained of any reasonable size. Discs 2 inches in

diameter cost about £1 per dozen, discs 3 inches in diameter about

10s. each. The price of discs increases enormously with the size. A

16-inch disc will cost about £100.

For special purposes, where the desired quality of glass does not

appear on the list, an application may be made to the Jena Factory of

Herr Schott. In order to give a definite example, I may mention that

for ordinary telescopic objectives good results may be obtained by

combining the hard crown and dense flint of Chance's list, using the

crown to form a double convex, and the flint to form a double concave

lens. The convex lens is placed in the more outward position in the

telescope, i.e. the light passes first through it.

The conditions to be fulfilled are:

(1) The glass must be achromatic;

(2) it must have a small spherical aberration for rays converging to

the principal focus.

It is impossible to discuss these matters without going into a

complete optical discussion. The radii of curvature of the surfaces,

beginning with the first, i.e. the external face of the convex lens,

are in the ratio of 1, 2, and 3; an allowance of 15 inches focal

length per inch of aperture is reasonable (see Optics in Ency.

Brit.), and the focal length is the same as the greatest radius of

curvature. Thus, for an object glass 2 inches in diameter, the first

surface of the convex lens would have a radius of curvature of 10

inches, the surface common to the convex and concave lens would have a

radius of curvature of 20 inches, and the last surface a radius of

curvature of 30 inches. This would also be about the focal length of

the finished lens. The surfaces in contact have, of course, a common

curvature, and need not be cemented together unless a slight loss of

light is inadmissible.

I will assume that a lens of about 2 inches diameter is to be made by

hand, i.e. without the help of a special grinding or polishing

machine; this can be accomplished perfectly well, so long as the

diameter of the glass is not above about 6 inches, after which the

labour is rather too severe. The two glass discs having been obtained

from the makers, it will be found that they are slightly larger in

diameter than the quoted size, something having been left for the

waste of working.

It is difficult to deal with the processes of lens manufacture without

entering at every stage into rather tedious details, and, what is

worse, without interrupting the main account for the purpose of

describing subsidiary instruments or processes. In order that the

reader may have some guide in threading the maze, it is necessary that

he should commence with a clear idea of the broad principles of

construction which are to be carried out. For this purpose it seems

desirable to begin by roughly indicating the various steps which are

to be taken.

(1) The glass is to be made circular in form and of a given diameter.

(2) Called Rough Grinding. The surfaces of the glass are to be made

roughly convex, plane, or concave, as may be required; the glass is to

be equally thick all round the edge. In this process the glass is

abraded by the use of sand or emery rubbed over it by properly shaped

pieces of iron or lead called "tools."

(3) The glass is ground with emery to the correct spherical figure as

given by a spherometer.

(4) Called Fine Grinding. The state of the surface is gradually

improved by grinding with finer and finer grades of emery.

(5) The glass is polished by rouge.

(6) The glass is "figured." This means that it is gradually altered in

form by a polishing tool till it gives the best results as found by

trial.

In processes 2 to 5 counterpart tool surfaces are required--as a rule

two convex and two concave surfaces for each lens surface. These

subsidiary surfaces are worked (i.e. ground) on discs of cast iron

faced with glass, or on slate discs; and discs thus prepared are

called "tools."

Taking these processes in the order named, the mode of manufacture is

shortly as follows:-

(1) The disc of glass, obtained in a roughly circular form, is mounted

on an ordinary lathe, being conveniently cemented by Regnault's mastic

to a small face plate. The lathe is rotated slowly, and the glass is

gradually turned down to a circular figure by means (1) of a tool with

a diamond point; or (2) an ordinary hand-file moistened with

kerosene, as described in § 42; or (3) a mass of brass or iron served

with a mixture of emery--or sand--and water fed on to the disc, so

that the disc is gradually ground circular.

The operation of making a circular disc of given diameter does not

differ in any important particular from the similar operation in the

case of brass or iron, and is in fact merely a matter of turning at a

slow speed.

(2 and 3) Roughing or bringing the surfaces of the glass roughly to

the proper convex or concave shape. This is accomplished by

grinding, generally with sand in large works, or with emery in the

laboratory, where the time saved is of more importance than the value

of the emery.

Discs of iron or brass are cast and turned so as to have a diameter

slightly less than that of the glass to be ground, and are, say, half

an inch thick. These discs are turned convex or concave on one face

according as they are to be employed in the production of concave or

convex glass surfaces. The proper degree of convexity or concavity

may be approximated to by turning with ordinary turning tools, using a

circular arc cut from zinc or glass (as will be described) as a

"template" or pattern. This also is a mere matter of turning.

The first approximation to the desired convex or concave surface of

the glass is attained (in the case of small lenses, say up to three

inches diameter) by rotating the glass on the lathe as described above

(for the purpose of giving it a circular edge) and holding the tool

against the rotating glass, a plentiful supply of coarse emery and

water, or sand and water, being supplied between the glass and metal

surfaces. The tool is held by hand against the surface of the

revolving glass, and is constantly moved about, both round its own

axis of figure and to and fro across the glass surface. In this way

the glass gradually gets convex or concave.

The curvature is tested from time to time by a spherometer, and the

tool is increased or decreased in curvature by turning it on a lathe

so as to cause it to grind the glass more at the edges or in the

middle according to the indications of the spherometer.

This instrument, by the way--so important for lens makers--consists

essentially of a kind of three-legged stool, with an additional leg

placed at the centre of the circle circumscribing the other three.

This central leg is in reality a fine screw with a very large head

graduated on the edge, so that it is easy to compute the fractions of

a turn given to the screw. The instrument is first placed on a flat

plate, and the central screw turned till its end just touches the

plate, a state of affairs which is very sharply discernible by the

slight rocking which it enables the instrument to undergo when pushed

by the hand. See the sketch.

On a convex or concave surface the screw has to be screwed in or out,

and from the amount of screwing necessary to bring all four points

into equal contact, the curvature may be ascertained.

Let a be the distance between the equidistant feet, and d the distance

through which the screw is protruded or retracted from its zero

position on a flat surface. Then the radius of curvature rho is given

by the formula 2rho = a2/3d +d.

Fig. 43.

The process of roughing is not always carried out exactly as

described, and will be referred to again.

(4) The glass being approximately of the proper radius of curvature on

one side, it is reversed on the chuck and the same process gone

through on the other side. After this the glass is usually dismounted

from the lathe and mounted by cement on a pedestal, which is merely a

wooden stand with a heavy foot, so that the glass may be held

conveniently for the workman. Sometimes a pedestal about four feet

high is fixed in the floor of the room, so that the workman engaged in

grinding the lens may walk round and round it to secure uniformity.

For ordinary purposes, however, a short pedestal may be placed on a

table and rotated from time to time by hand, the operator sitting down

to his work.

Rough iron or brass tools do not succeed for fine grinding--i.e.

grinding with fine emery, because particles of emery become embedded

in the metal so tightly that they cannot be got out by any ordinary

cleaning. If we have been using emery passing say a sieve with 60

threads to the inch, and then go on to some passing say 100 threads to

the inch, a few of the coarser particles will adhere to the "tool",

and go on cutting and scratching all the time grinding by means of the

finer emery is in progress.

To get over this it is usual to use a rather different kind of

grinding tool. A very good kind is made by cementing small squares of

glass (say up to half an inch on the side), on to a disc of slate

slightly smaller than the lens surface to be formed (Fig. 51). The

glass-slate tool is then "roughed" just like the lens surface, but, of

course, if the lens has been roughed "convex" the tool must be roughed

"concave".

The "roughed" tool is then used to gradually improve the fineness of

grinding of the glass. For this purpose grinding by hand is resorted

to, the tool and lens being supplied continually with finer and finer

emery. Fig. 52 gives an idea of the way in which the tool is moved

across the glass surface. Very little pressure is required. The tool

is carried in small circular sweeps round and round the lens, so that

the centre of the tool describes a many-looped curve on the lens

surface. The tool must be allowed to rotate about its own axis; and

the lens and pedestal must also be rotated from time to time.

Every few minutes the circular strokes are interrupted, and simple,

straight, transverse strokes taken. In no case (except to correct a,

defect, as will be explained) should the tool overhang the lens

surface by more than about one quarter the diameter of the latter.

After grinding say for an hour with one size of emery fed in by means

of a clean stick say every five minutes, the emery is washed off, and

everything carefully cleaned. The process is then repeated with finer

emery, and so on.

The different grades of emery are prepared by taking advantage of the

fact that the smaller the particles the longer do they remain

suspended in water. Some emery mud from a "roughing" operation is

stirred up with plenty of water and left a few seconds to settle, the

liquor is then decanted to a second jug and left say for double the

time, say ten seconds; it is decanted again, and so on till four or

five grades of emery have been accumulated, each jug containing finer

emery than its predecessor in the process.

It is not much use using emery which takes more than half an hour to

settle in an ordinary bedroom jug. What remains in the liquid to be

decanted is mostly glass mud and not emery at all. The process of

fine grinding is continually checked by the spherometer, and the art

consists in knowing how to move the grinding tool so as to make the

lens surface more or less curved. In general it may be said that if

the tool is moved in small sweeps, and not allowed to overhang much,

the Centre of the lens will be more abraded, while if bold free

strokes are taken with much overhanging, the edges of the lens will be

more ground away.

By the exercise of patience and perseverance any one will succeed in

gradually fine grinding the lens surface and keeping it to the

spherometer, but the skill comes in doing this rapidly by varying the

shape of the strokes before any appreciable alteration of curvature

has come about.

Polishing.

The most simple way of polishing is to coat the grinding tool with

paper, as will be described, and then to brush some rouge into the

paper. The polisher is moved over the work in much the same way as

the fine grinding tool, until the glass is polished. Many operators

prefer to use a tool made by squeezing a disc of slate, armed with

squares of warm pitch, against the lens surface (finely ground), and

then covering these squares with rouge and water instead of emery and

water as in the fine grinding process.

The final process is called "figuring." It will in general be

unnecessary with a small lens. With large lenses or mirrors the final

touches have to be given after the optical behaviour of the lens or

mirror has been tested with the telescope itself, and this process is

called "figuring." A book might easily be written on the optical

indications of various imperfections in a mirror or lens. Suffice it

to say here that a sufficiently skilled person will be able to decide

from an observation of the behaviour of a telescope whether a lens

will be improved by altering the curvature of one or all of the

surfaces.

A very small alteration will make a large difference in the optical

properties, so that in general "figuring" is done merely by using the

rouge polishing tool as an abrading tool, and causing it to alter the

curves in the manner already suggested for grinding. There are other

methods based on knocking squares out of the pitch-polisher so that

some parts of the glass may be more abraded than others.

The "figuring" and polishing may be done by hand just like the

grinding. There are machines, however, which can be made to execute

the proper motions, and a polisher is set in such a machine, and the

mechanical work done is by no means inconsiderable. In fact for

surfaces above six inches in diameter few people are strong enough to

work a polisher by hand owing to the intense adhesion between it and

the exactly fitting glass surface.

Such is a general outline of the processes required to produce a lens

or mirror. These processes will now be dealt with in much greater

detail, and a certain amount of repetition of the above will

unfortunately be necessary: the reader is asked to pardon this. It

will also be advisable for the reader to begin by reading the whole

account before he commences any particular operation. The reason for

this is that it has been desirable to keep to the main account as far

as possible without inserting special instructions for subsidiary

operations, however important they may be; consequently it may not

always be quite clear how the steps described are to be performed. It

will be found, however, that all necessary information is really

given, though perhaps not always exactly in the place the reader might

at first expect.

§ 54. All the discs that I have seen, come from the makers already

roughly ground on the edges to a circular figure--but occasionally the

figure is very rough indeed--and in some cases, especially if small

lenses have to be made, it is convenient to begin by cutting the glass

discs out of glass sheet, which also may be purchased of suit-able

glass. To do this, the simplest way is to begin by cutting squares

and then cutting off the corners with the diamond, the approximate

circular figure being obtained by grinding the edges on an ordinary

grindstone.

If the pieces are larger, time and material may be saved by using a

diamond compass, i.e. an ordinary drawing compass armed with a

diamond to cut circles on the glass, and breaking the superfluous

glass away by means of a pair of spectacle-maker's shanks (Fig. 44),

or what does equally well, a pair of pliers with soft iron jaws. With

these instruments glass can be chipped gradually up to any line,

whether diamond-cut or not, the jaws of the pincers being worked

against the edge of the glass, so as to gradually crush it away.

Fig. 44.

Assuming that the glass has been bought or made roughly circular, it

must be finished on the lathe. For this purpose it is necessary to

chuck it on an iron or hardwood chuck, as shown in Fig. 46. For a

lens below say an inch in diameter, the centering cement may be used;

but for a lens of a diameter greater than this, sufficient adhesion is

easily obtained with Regnault's mastic, and its low melting point

gives it a decided advantage over the shellac composition.

The glass may be heated gradually by placing it on the water bath, or

actually in the water, and gradually bringing the water up to the

boiling-point. The glass, being taken out, is rapidly wiped, and

rubbed with a bit of waste moistened, not wet, with a little

turpentine: its surface is then rubbed with a stick of mastic

previously warmed so as to melt easily. The surface of the chuck

being also warm, and covered with a layer of melted cement, it is

applied to the glass. The lathe is turned slowly by hand, and the

glass pushed gradually into the most central position; it is then

pressed tight against the chuck by the back rest, a bit of wood being

interposed for obvious reasons.

When all is cold the turning may be proceeded with. The quickest way

is to use the method already described (i.e. actual turning by a file

tool); but if the student prefers (time being no object), he may

accomplish the reduction to a circular form very easily by grinding.

Fig. 45.

Fig. 46.

For this purpose he will require to make the following arrangements

(Fig. 45). If the lathe has a slide rest, a piece of stout iron may

be bent and cut so as to fit the tool rest, and project beneath the

glass. The iron must be fairly rigid, for if it springs appreciably

beneath the pressure of the glass, it will not grind the latter really

round. The lathe may run rather faster than for turning cast iron of

the same size. Coarse emery, passing through a sieve of 80 threads to

the inch (run), may be fed in between the glass and iron, and the

latter screwed up till the disc just grinds slightly as it goes round.

A beginner will generally (in this as in all cases of grinding

processes) tend to feed too fast--no grinding process can be hurried.

If a slide rest is not available, a hinged board, carrying a bit of

iron, may (see Fig. 45) be arranged so as to turn about its hinge at

the back of the lathe; and it may be screwed up readily enough by

passing a long set-screw through the front edge, so that the point of

the screw bears upon the lathe bed. I may add that emery behaves as

if it were greasy, and it is difficult to wet it with clean water.

This is easily got over by adding a little soap or alcohol to the

water, or exercising a little patience.

A good supply of emery and water should be kept between the disc and

the iron; a little putty may be arranged round the point of contact

on the iron to form a temporary trough. In any case the resulting

emery mud should on no account be thrown away, but should be carefully

kept for further use. The process is complete when the glass is

perfectly round and of the required diameter as tested by callipers.

§ 55. The next step is to rough out the lens, and this may easily be

done by rotating it more slowly, i.e. with a surface speed of ten

feet per minute, and turning the glass with a hard file, as explained

in § 42. If it is desired to employ the slide rest, it is quicker and

better to use a diamond tool--an instrument quite readily made, and

of great service for turning emery wheels and the like,--a thing, in

fact, which no workshop should be without. A bit of diamond bort, or

even a clear though off-colour stone, may be employed.

An ordinary lathe tool is prepared by drawing down the tool steel to a

long cone, resembling the ordinary practice in preparing a boring

tool. The apex of the cone must be cut off till it is only slightly

larger than the greatest transverse diameter of the diamond splinter.

The latter may have almost any shape--a triangular point, one side of

a three-sided prism is very convenient. A hole is drilled in the

steel (which must have been well softened), only just large enough to

allow the diamond to enter--if the splinter is thicker in the middle

than at either end, so much the better--the diamond is fastened in

position by squeezing the soft steel walls tightly down upon it.

Personally I prefer to use a tool holder, and in this case generally

mount the diamond in a bit of brass rod of the proper diameter; and

instead of pinching in the sides of the cavity, I tin them, and set

the diamond in position with a drop of soft solder.

Fig. 47.

In purchasing diamond bort, a good plan is to buy fragments that have

been employed in diamond drilling, and have become too small to reset;

in this case some idea as to the hardness of the bits may be obtained.

Full details as to diamond tool-making are given in books on

watch-making, and in Holtzapffell's great work on Mechanical

Manipulation; but the above notes are all that are really

necessary--it is, in fact, a very simple matter. The only advantage of

using a diamond tool for glass turning is that one does not need to be

always taking it out of the rest to sharpen it, which generally happens

with hard steel, especially if the work is turned a little too fast.

I recommend, therefore, that the student should boldly go to work

"free hand" with a hard file; but if he prefer the more formal

method, or distrust his skill (which he should not do), then let him

use a diamond point, even if he has the trouble of making it. When

using a diamond it is not necessary to employ a lubricant, but there

is some advantage in doing so.

The surface of the lens can be roughly shaped by turning to a template

or pattern made by cutting a circular arc (of the same radius as the

required surface) out of a bit of sheet zinc. Another very handy way

of making templates of great accuracy is to use a beam compass

(constructed from a light wooden bar) with a glazier's diamond instead

of a pencil. A bit of thin sheet glass is cut across with this

compass to the proper curvature--which can be done with considerable

accuracy and the two halves of the plate, after breaking along the

cut, are ground together with a view to avoiding slight local

irregularities, by means of a little fine emery and water laid between

the edges. In this process the glass is conveniently supported on a

clean board or slate, and the bits are rubbed backwards and forwards

against each other.

§ 56. It is not very easy for a beginner to turn a bit of

anything--iron, wood, or glass--with great accuracy to fit a template,

and consequently time may be saved by the following procedure, applied as

soon as the figure of the template is roughly obtained. A disc of

lead or iron, of the same diameter as the glass, and of approximately

the proper curvature, is prepared by turning, and is armed with a

handle projecting coaxially from the back of the disc. The glass

revolving with moderate speed on the lathe, the lead tool, supplied

with coarse emery and water, is held against it, care being taken to

rotate the tool by the handle, and also to move it backwards and

forwards across the disc, through a distance, say, up to half an inch;

if it is allowed to overhang too much the edges of the glass disc will

be overground. By the use of such a tool the glass can readily be

brought up to the template.

The only thing that remains, so far as the description of this part of

the process goes, is to give a note or two as to the best way of

making the lead tools, and for this purpose the main narrative of

processes must be interrupted. The easiest way is to make a set of

discs to begin with. For this purpose take the mandrel out of the

lathe, and place it nose downwards in the centre of an iron ring of

proper diameter on a flat and level iron plate.

The discs are made by pouring lead round the screw-nose of the

mandrel. This method, of course, leaves them with a hole in the

centre; but this can be stopped up by placing the hot disc (from

which the mandrel has been unscrewed) on a hot plate, and pouring in a

sufficiency of very hot lead; or, better still, the mandrel can be

supported vertically at any desired distance above the plate while the

casting is being poured. Lead discs prepared in this way are easily

turned so as to form very convenient chucks for brass work, and for

use in the case now being treated, they are easily turned to a

template, using woodturners' tools, which work better if oiled, and

must be set to cut, not scrape.

If the operator does not mind the trouble of cutting a screw, or if he

has a jaw chuck, the lead may be replaced by iron with some advantage.

The following is a neat way of making concave tools. It is an

application of the principle of having the cutting tool as long as the

radius of curvature, and allowing it to move about the centre of

curvature. Place the disc of iron or lead on the lathe mandrel or in

the chuck, and set the slide rest so that it is free to slide up or

down the lathe bed. Take a bar of tool steel and cut it a little

longer than the radius of curvature required. Forge and finish one

end of the bar into a pointed turning tool of the ordinary kind.

Measure the radius of curvature from the point of the tool along the

bar, and bore a hole, whose centre is at this point, through the bar

from the upper to the lower face. I regard the upper face as the one

whose horizontal plane contains the cutting point when the tool is in

use. Clamp a temporary back centre to the lathe bed, and let it carry

a pin in the vertical plane through the lathe centres, and let this

pin exactly fit the hole in the bar.

Fig. 48.

Place the "radius" tool in position for cutting, and let it be lightly

held in the slide rest nearly at the cutting point, the centre of

rotation of the pedestal (or its equivalent) passing through the

central line of the bar. Then adjust the temporary back rest, so that

the tool will take a cut. In the sketch the tool is shown swinging

about the back centre instead of about a pin--there is little to

choose between the methods unless economy of tool steel is an object.

The tool must now be fed across the work. The pedestal must of course

be free to rotate, and the slide rest to slip up and down the bed. In

this way a better concave grinding tool can be made than would be made

by a beginner by turning to a template--though an expert turner would

probably carry out the latter operation so as to obtain an' accuracy

of the same order, and would certainly do it in much less time than

would be required in setting up the special arrangements here

described.

On the other hand, if several surfaces have to be prepared, as in the

making of an achromatic lens, the quickest way would be by the use of

the radius tool, bored of course to work at the several radii

required. I have tried both methods, and my choice would depend

partly on the lathe at my disposal, and partly on the number of

grinding tools that had to be prepared.

Having obtained a concave tool of any given radius, it is easily

copied--negatively, so as to make a convex tool in the following

manner. Adjust the concave tool already made on the back rest, so

that if it rotated about the line of centres, it would rotate about

its axis of figure.

Arrangements for this can easily be made, but of course they will

depend on the detailed structure of the lathe. Use the slide rest as

before, i.e. let it grasp an ordinary turning tool lightly, the

pedestal being fixed, but the rest free to slide up or down the lathe

bed. Push the back rest up till the butt of the turning tool (ground

to a rounded point) rests against the concave grinding tool. If the

diameter of the convex tool required be very small compared with the

radius of curvature of the surface (the most usual case), it is only

necessary to feed the cutting tool across to "copy" the concave

surface sufficiently nearly.

Fig. 49.

There seems no reason, however, why these methods should not be

applied at once to the glass disc by means of a diamond point, and the

rough grinding thus entirely avoided. I am informed that this has

been done by Sir Henry Bessemer, but that the method was found to

present no great advantage in practice. A reader with a taste for

mechanical experimenting might try radius bar tools with small

carborundum wheels rapidly driven instead of a diamond.

Enough has now been said to enable any one to prepare rough convex or

concave grinding tools of iron or lead, and of the same diameter as

the glass to be ground.

The general effect of the process of roughing the rotating lens

surface is to alter the radius of curvature of both tool and glass;

hence it is necessary to have for each grinding tool another to fit

it, and enable it to be kept (by working the two together) at a

constant figure. After a little practice it will be found possible to

bring the glass exactly up to the required curvature as tested by

template or spherometer. The art of the process consists in altering

the shape of the grinding tool so as to take off the glass where

required, as described in § 53, and from this point of view lead has

some advantages; (opinions vary as to the relative advantages of lead

and iron tools for this purpose, however). The subsidiary grinding

tool is not actually needed for this preliminary operation, but it has

to be made some time with a view to further procedure, and

occasionally is of service here.

§ 57. 'The glass disc must be ground approximately to the proper

curvature on each side before any fine grinding is commenced. It is

precisely for this purpose that the previous turning of the disc is

recommended, for it is easy to unmount and recentre a round object,

but not so easy if the object have an indefinite shape. Using a

cement which is plastic before it sets, the disc may be easily taken

off the chuck and centred by a little handicraft, i.e. by rotating

the lathe slowly and pushing the disc into such a position that it

rotates about its axis. The grinding of the second surface is

accomplished exactly as in the former case; of course on reversing

the glass the chuck has to be slightly turned up to fit the convex or

concave surface.

§ 58. There is, however, one point of interest and importance--attention

to which will save a good deal of useless labour afterwards.

The glass must be ground in such a manner that the thickness at the

edge is the same all round. In other words, the axes of figure of the

two surfaces must coincide. This will be the case if the recentering

has been accurately performed, and therefore no pains should be spared

to see that it is exactly carried out. Any simple form of vernier

gauge (such as Brown and Sharpe's vernier callipers) will serve to

allow of a sufficiently accurate measurement of the edge thickness of

the lens. If any difference of thickness is observed as the gauge

moves round the edge, one or other of the surfaces must be reground.

Of course the latitude of error which may be permitted depends so much

on the final arrangements for a special finishing process called the

"centering of the lens"--which will be described--that it is

difficult to fix a limit, but perhaps one-thousandth of an inch may be

mentioned as a suitable amount for a 2-inch disc. For rough work, of

course; more margin may be admitted.

§ 59. In a large shop I imagine that lenses of only two inches

diameter would be ground in nests; or, in other words, a number would

be worked at a time, and centering, even of a rough kind, would be

left to the last; but this process will be treated hereafter. At

present I shall assume that only one lens will be made at a time.

Consequently we now enter on the stage of fine grinding by hand. A

leaden pedestal, for the sake of stability, must be provided on which

to mount the lens, so that the surface to be operated on may be nearly

horizontal (Fig. 50). Before this can be done, however, fresh

grinding tools (two for each surface) must be properly prepared.

After trying several plans I unhesitatingly recommend that all

fine-grinding surfaces should be made of glass. This is easily done

by taking two discs of lead, or iron, or slate, cut to a one-tenth

inch smaller radius of curvature (in the case of a convex tool, and

the opposite in the other case) than the lens surface (Fig. 51, A).

On these, square bits of sheet glass, one-tenth of an inch thick, are

to be cemented, so as to leave channels of about one-eighth of an inch

between each bit of glass (Fig. 52, B). The "mastic" cement

formerly described may be employed for this purpose.

Fig. 50.

The bits of glass ought first to have their edges dressed smooth on

the grind-stone. A convex and concave glass surface having been thus

roughly prepared, they must be mounted in turn in the lathe, and

brought to the proper curvature by grinding with the tools formerly

employed and tested by the template or spherometer. It is well to

control this process by means of a spherometer, so that the desired

radius may be approximately reached. The two glass-grinding tools

are then ground together by hand (see § 53 and § 61), the spherometer

being employed from time to time to check the progress of the work.

In general, if large circular sweeps are taken, greatly overhanging

the side of the glass surface to be figured, both the upper and lower

surfaces will be more ground at the edges, while in the opposite

event the centre will be chiefly affected.

Fig. 51.

A spherometer capable of measuring a 2-inch surface may be procured,

having a screw of, say, 50 threads to the inch, and a micrometer

surface divided into 200 parts, each part easily capable of

subdivision--into tenths or even twentieths. To get the full

advantage of the spherometer it must screw exceedingly freely (i.e.

must be well oiled with clock oil), and must not be fingered except at

the milled head. If one of the legs is held by the fingers the

expansion is sufficient to throw the instrument quite out of

adjustment. The glass-grinding tools being brought to the proper

figure, the next process is to transfer the same to the lens, and this

is done by similar means, the fellow tool being used to correct the

one employed in grinding the lens surface. Before the grade of emery

is changed all three surfaces must agree, as nearly, at least, as the

spherometer will show.

In order to prevent confusion the following summary of the steps

already taken may be given. The discs of glass are first ground or

turned so as to be truly circular. Four "tools" are made for each

surface--a rough pair of iron or lead, and a finishing pair of iron,

lead, or slate faced by glass squares. For a small lens the iron or

lead backing may be used, for a large one the slate. The rough tools

are used to give an approximate figure both to the lens and to the

finishing tools.

The final adjustment is attained by grinding one of the glass-faced

tools alternately upon the lens and upon the fellow glass-faced tool.

The spherometer is accepted at all stages of the process as the final

arbiter as to curvature. Some hints on the form of strokes used in

grinding will be given later on (see § 61). It suffices to state here

that the object throughout is to secure uniformity by allowing both

the work and the tool to rotate, and exercising no pressure by the

fingers. The tool backing may weigh from one to two pounds for a

2-inch lens.

§ 60. The tools and lens being all of the same curvature, the state

of the surface is gradually improved by grinding with finer and finer

emery. The best way of grading the emery is by washing it with clean

water, and allowing the emery (at first stirred up with the water) to

settle out. The longer the time required for this part of the process

the finer will be the emery deposited. An ordinary bedroom jug is a

very good utensil to employ during this process; a large glass jug is

even better. The following grades will be found sufficient, though I

daresay every operative's practice differs a little on this point.

1st grade: Flour emery, with the grit washed out, i.e. allowed to

stand for 2" (sec.) before being poured off.

2nd grade: Stand 5" (secs.), settle in 1' (min.)

3rd grade: Stand 1', settle in 10'.

4th grade: Stand 10', settle in 60'.

It is generally advisable to repeat the washing process with each

grade. Thus, selecting grade 2 for illustration, the liquor for grade

3 must be poured off without allowing any of the sediment to pass over

with it. If any sediment at all passes, one has no security against

its containing perhaps the largest particle in the jug. As soon as

the liquor for No. 3 has been decanted, jug No. 2 is filled up again

with clean water (filtered if necessary), and after standing 5" is

decanted into jug No. 2b, the sediment is returned to jug No. 1, and

the liquor, after standing 1', is transferred to jug No. 3.

The greatest care is necessary at each step of the operation to

prevent "sediment" passing over with liquor. There is a little danger

from the tendency which even comparatively large particles of emery

have to float, in consequence of their refusing to get wet, and the

emery worked up on the side of the jug is also a source of danger,

therefore wipe the jug round inside before decanting.

In order to get a uniform grade stop the currents of water in the jug,

which may work up coarse particles, by holding a thin bit of wood in

the rotating liquid for a moment, and then gently withdrawing it in

its own plane. These precautions are particularly necessary in the

case of grades Nos. 2, 3, and 4, especially No. 4, for if a single

coarse particle gets on the tool when the work has progressed up to

this point it will probably necessitate a return to grinding by means

of No. 2, and involve many hours' work.

The surface of the lens will require to be ground continuously with

each grade till it has the uniform state of roughness corresponding to

the grade in question. Two hours for each grade is about the usual

time required in working such a lens as is here contemplated.

The coarser grades of emery may be obtained by washing ordinary flour

of emery, but the finer ones have to be got from emery which has been

used in the previous processes. It is not a good plan to wash the

finer grades of emery out of the proceeds of very rough grinding say

with anything coarser than flour of emery--as there is a danger of

thereby contaminating the finer grades with comparatively coarse glass

particles (owing to their lightness) and this may lead to scratching.

If the finer grades are very light in colour, it may be inferred that

a considerable portion of the dust is composed of glass, and this does

no good. Consequently time may be saved by stirring up the

light-coloured mass with a little hydrofluoric acid in a platinum

capsule; this dissolves the finely divided glass almost

instantaneously. The emery and excess of hydrofluoric acid may then

be thrown into a large beaker of clean water and washed several times.

Fine emery thus treated has much the same dark chocolate colour as the

coarser varieties.

The operator should not wear a coat, and should have his arms bare

while working with fine emery, for a workshop coat is sure to have

gathered a good deal of dust, and increases the chances of coarse

particles getting between the surfaces.

§ 61. Details of the Process of Fine Grinding.

A lens of the size selected for description is mounted as before

mentioned on a leaden pedestal, and the operator places the latter on

a table of convenient height in a room as free from dust as possible.

Everything should be as clean as a pin, and no splashes of emery mud

should be allowed to lie about. I have found it convenient to spread

clean newspapers on the table and floor, and to wear clean linen

clothes, which do not pick up dust. I have an idea that in large

workshops some simpler means of avoiding scratches must have been

discovered, but I can only give the results of my own experience. I

never successfully avoided scratches till I adopted the precautions

mentioned.

Fig. 52.

The left hand should be employed in rotating the pedestal either

continuously (though slowly) or at intervals of, say, one minute.

This point is rather important. Some operators require two hands to

work the grinding tool, and in any case this is the safer practice.

Under these circumstances the pedestal may be rotated through

one-eighth or tenth of a revolution every three minutes, or

thereabouts. The general motion given to the grinding tool should be

a series of circular sweeps of about one-fourth the diameter of the

glass disc, and gradually carried round an imaginary circle drawn on

the surface of the lens and concentric with it (Fig. 52).

The tool may overhang the lens by a quarter of the diameter of the

latter as a maximum. The circuit may be completed in from twelve to

thirty sweeps. The grinding tool should be lightly held by the

fingers and the necessary force applied parallel to the surface. The

tool itself must be slowly rotated about its axis of figure. If the

tool be lightly held, it will be found that it tends to rotate by

itself. I say "tends to rotate," for if the tool be touching evenly

all over the surface it will rotate in a direction opposite to the

direction of the circular sweep. For instance, if the tool be carried

round its looped path clockwise, it will tend to rotate about its own

axis of figure counter-clockwise. If it touch more in the middle,

this rotation will be increased, while if it touches more along the

edge, the rotation will be diminished, or even reversed in an extreme

case.

Every fifty sweeps or so the tool should be simply ground backwards

and forwards along a diameter of the lens surface. This grinding

should consist of three or four journeys to and fro along, say, eight

different diameters. About one-quarter of the whole grinding should

be accomplished by short straight strokes, during which the tool

should only overhang about one-quarter of an inch. The object of the

straight strokes is to counteract the tendency to a gradual

accumulation of the emery in the centre, which results from the

circular grinding.

A great deal of the art of the process consists in knowing how to work

the tool to produce any given effect. For instance, if the lens

requires to be ground down near the centre, the epicycloidal strokes

must be nearly central; the tool must never overhang very much. If,

on the other hand, it is the edges which require attention, these must

be dealt with by wider overhanging strokes. The tool must be

frequently tested on its fellow, and, indeed, ground upon it if any

marked unevenness of action (such as that just described) is required

for the lens. A check by spherometer will be applied at intervals

according to the judgment of the operator, but, in any case, the

fellow tool and lens should be kept at very nearly the same figure.

The emery should never be allowed to become anything like dry between

the tool and the lens, for in some way (probably by capillary action

increasing the pressure of the tool) this seems to lead to scratching

and "rolling" of the emery. The channels in the glass tool between

the squares are of the greatest importance in enabling the emery to

distribute itself. Perhaps the best guide in enabling one to judge

as to when it is time to wash off the emery and apply fresh is the

"feel" of the tool; also when the mud gets light in colour we know

that it is full of glass dust, and proportionately inoperative.

New emery may be put on, say, every five minutes, but no absolute rule

can be given, for much depends on the pressure of the tool upon the

lens. In the case considered a brass or lead, or even slate tool, of

an inch, or even less, in thickness, will press quite heavily enough.

In washing the lens and tool before new emery is introduced, a large

enamelled iron bucket is very handy; the whole of the tool should be

immersed and scrubbed with a nail-brush. The lens surface may be

wiped with a bit of clean sponge, free from grit, or even a clean damp

cloth.

When the time comes to alter the grade of emery, a fresh lot of

newspapers should be put down, and tools, lens, and pedestal well

washed and brushed by the nail-brush. The surfaces should be wiped

dry by a fresh piece of rag, and examined for scratches and also for

uniformity of appearance; a good opinion can be formed as to the fit

of the surfaces by noting whether--and if so, to what degree--they

differ in appearance from point to point when held so that the light

falls on them obliquely.

It is necessary to exercise the greatest care in the washing between

the application of successive grades of emery, and this will be

facilitated if the edges of the glass squares were dressed on a

grindstone before they were mounted. An additional precaution which

may be of immense advantage is to allow the tool to dry between the

application of successive grades of emery (of course, after it has

been scrubbed), and then to brush it vigorously with a hat-brush. It

sometimes happens that particles of mud which have resisted the wet

scrubbing with the nail-brush may be removed by this method.

As my friend Mr. Cook informs me that his present practice differs

slightly from the above, I will depart from the rule I laid down, and

add a note on an alternative method.

Consider a single lens surface. This is roughed out as before by an

iron tool, a rough fellow tool being made at the same time. The

squares of glass are cemented to the roughing tool, and this is ground

to the spherometer by means of the counterpart tool. The glass-coated

tool is then applied to the lens surface and grinding with the first

grade of emery commenced. The curvature is checked by the

spherometer. Two auxiliary tools of, say, half the diameter of the

lens, are prepared from slate, or glass backed with iron, and applied

to grind down either the central part of the lens surface or tool

surface, according to the indications of the spherometer. Any changes

that may occur during grinding are corrected by these tools. The

spherometer is accepted as the sole guide in obtaining the proper

curvature. A slate backing is preferred for tools of any diameter

over, say, 2 inches.

§ 62. Polishing.

After the surface has been ground with the last grade of emery, and

commences to become translucent even when dry, the grinding may be

considered to be accomplished, and the next step is the polishing.

There are many ways of carrying out this process, and the relative

suitability of these methods depends on a good many, so to speak,

accidental circumstances. For instance, if the intention is to finish

the polishing at a sitting, the polishing tool may be faced with

squares of archangel--not mineral or coal-tar--pitch and brought to

shape simply by pressing while warm against the face of the lens. A

tool thus made is very convenient, accurate, and good, but it is

difficult to keep it in shape for any length of time; if left on the

lens it is apt to stick, and if it overhangs ever so little will, of

course, droop at the edges.

On the whole, the following will be found a good and sufficient plan.

The glass-grinding tool is converted into a polishing tool by pasting

a bit of thin paper over its surface; a bit of woven letter paper of

medium thickness with a smooth but not glazed surface does very well.

We have found that what is called Smith's "21 lbs. Vellum Wove" is

excellent. This is steeped in water till quite pliable and almost

free from size. The glass tool is brushed over with a little thin

arrowroot or starch paste, and the paper is laid upon it and squeezed

down on the glass squares as well as possible; if the paper is wet

enough and of the proper quality it will expand sufficiently to

envelop the tool without creases, unless the curvature is quite out of

the common.

This being accomplished, and the excess of water and paste removed,

the face of the paper is (for security) washed with a little clean

water and a bit of sponge, and, finally, the tool is slightly pressed

on the lens so as to get the paper to take up the proper figure as

nearly as possible. After the polishing tool has been thus brought to

the proper figure, it is lifted off and allowed to dry slowly. When

the paper is dry it may be trimmed round the edges so as not to

project sensibly beyond the glass squares. The next step is to brush

the surface over very carefully with polishing rouge (prepared as is

described at the end of this section) by means of a hat-brush. When

the surface of the paper is filled with rouge all excess must be

removed by vigorous brushing.

Fig. 53.

The tool being placed on the lens, two or three strokes similar to

those used in grinding may be taken, and the tool is then lifted off

and examined. It will be found to be dotted with a few bright points,

produced by the adhesion of glass at the places of contact. These

points are then to be removed in the following manner. An old

three-cornered file is ground on each side till the file marks

disappear, and sharp edges are produced (Fig. 53). This tool is used

as an ink eraser, and it will be found to scrape the paper of the

polishing tool very cleanly and well.

The bright spots are the objects of attention, and they must be erased

by the old file, and the polisher reapplied to the glass. A few

strokes will develop other points, more numerous than before, and

these in turn must be erased. The process is continued till the whole

surface of the polishing tool is evenly covered with bright specks,

and then the polishing may be proceeded with. The specks should not

be more than about one-eighth of an inch apart, or the polishing will

be irregular.

The operation of polishing is similar to that of grinding. A

reasonable time for polishing a glass surface is twenty hours; if

more time is required it is a sign that the fine grinding has not been

carried far enough. The progress of the operation may be best watched

by looking at the surface--not through it. For this purpose a good

light is requisite. When the lens is dismounted it may be examined by

a beam of sunlight in a dark room, under which circumstances the

faintest signs of grayness are easily discernible.

It may be mentioned here that if the surface is in any way scratched

the rouge will lodge in the scratches with great persistence, and an

expert can generally tell from the appearance of scratches what kind

of polishing powder has been employed.

The persistence with which rouge clings to a rough surface of glass is

rather remarkable. Some glass polishers prefer to use putty powder as

a polishing material, and it is sometimes said to act more quickly

than rouge; from my rather limited experience I have not found this

to be the case, but it may have merits that I do not know of. Is it

possible that its recommendation lies in the fact that it does not

render scratches so obtrusively obvious as rouge does?

Rouge is generally made in two or more grades. The softer grade is

used for polishing silver, and is called jewellers' rouge. The harder

grade, suitable for glass polishing, is best obtained from practical

opticians (not mere sellers of optical instruments). I mean people

like Messrs. Cook of York. Many years ago I prepared my own hard

rouge by precipitating ferrous sulphate solution by aqueous ammonia,

washing the precipitate, and heating it to a red heat. The product

was ground up with water, and washed to get rid of large particles.

This answered every purpose, and I could not find that it was in any

way inferior to hard rouge as purchased. The same precipitate heated

to a lower temperature is said to furnish a softer variety of rouge;

at all events, it gives one more suitable for polishing speculum

metal. Lord Rosso used rouge heated to a dull redness for this

purpose.

Rouge, whether made or bought, should always be washed to get rid of

grit. I ought to add that not the least remarkable fact about the

polishing is the extraordinarily small quantity of the polishing

material requisite, which suggests that the process of polishing is

not by any means the same as that of exceptionally fine grinding. Is

it possible that the chief proximate cause of the utility of rouge is

to be sought in its curious property of adhering to a rough glass

surface, causing it, so to speak, to drag the glass off in minute

quantities, and redeposit it after a certain thickness has been

attained on another part of the surface?

§ 63. Centering.

When a lens is ground and polished it will almost always happen that

the axis of revolution of its cylindrical edge is inclined to the axis

of revolution of its curved surfaces. Since in practice lenses have

to be adjusted by their edges, it is generally necessary to adjust the

edge to a cylinder about the axis of figure of the active surfaces.

This is best done on a lathe with a hollow mandrel.. The lens is

chucked on a chuck with a central aperture--generally by means of

pitch or Regnault's mastic, or "centering" cement for small

lenses--and a cross wire is fixed in the axis of revolution of the lathe,

and is illuminated by a lamp. This cross wire is observed by an

eye-piece (with cross wires only in the case of a convex lens, or a

telescope similarly furnished in the case of a concave lens),

also placed in the axis of rotation of the lathe.

Both cross wires are thus in the axis of revolution of the mandrel,

and the distant one (B in the figure) is viewed through the lens and

referred to the fixed cross wires at A. In general, as the lathe is

rotated by turning the mandrel the image of the illuminated cross

wires will be observed to rotate also. The lens is adjusted until the

image remains steady on rotating the mandrel and it is to give time

for this operation that a slow-setting cement is recommended. When

the image remains stationary we know that the optical centre of the

lens is in the axis of revolution, and that this axis is normal to

both lens surfaces, i.e. is the principal axis of the lens, or axis

of figure.

Fig. 54.

A much readier method, and one, in general, good enough for most

purposes, is to put a candle on the end of the lathe-bed where the

back centre generally is, and observe the images of the flame by

reflection from both the lens surfaces. This method is very handy

with small lenses; the mandrel is turned, and the lens adjusted by

hand till the images are immovable. In both cases, of course, the

edge of the lens is turned or ground till it is truly circular, the

position of the lens remaining undisturbed on the chuck. If the edge

gauge has been properly used in the earlier stages of figuring, it

will be found that very little turning or grinding is requisite to

produce a true centering.

The particular defect due to want of centering in a lens may be

observed by using it as the objective of a telescope, and observing a

star slightly out of focus. The interference fringes will not be

concentric circles unless the lens is properly centred. I ought to

say that I have not looked into the theory of this, but have merely

taken it as a generally admitted fact. The diseases of lenses and the

modes of treating them are dealt with in a book by Messrs. Cook of

York, entitled On the Adjustment and Testing of Telescopic Objectives.

The final process of figuring will be dealt with later on (§ § 66 and

67), as it applies not only to lenses but to mirrors, prisms, etc. If

the instructions given have been carefully carried out on a 2-inch

lens, it should perform fairly well, and possibly perfectly, without

any further adjustment of the glass.

§ 64. Preparation of Small Lenses, where great Accuracy is not of the

first Importance.

Such lenses may generally be made out of bits of good plate or sheet

glass, and are of constant use in the physical laboratory. They may

be purchased so cheaply, however, that only those who have the

misfortune to work in out-of-the-way places need be driven to make

them.

Suitable glass having been obtained and the curves calculated from the

index of refraction, as obtained by any of the ordinary methods

applicable to plates (the microscope method, in general, is quite good

enough), squares circumscribing the desired circles are cut out by the

help of a diamond. [Footnote: Glazebrook and Shaw's Practical

Physics, p. 383 (4th ed.).] The squares are roughly snipped by means

of a pair of pliers or spectacle-maker's shanks. The rough circles

are then mounted on the end of a brass or iron rod of rather greater

diameter than the finished lenses are to possess. This mounting is

best done by centering cement.

The discs are then dressed circular on a grindstone, the rod serving

both as a gauge and handle. A sufficient number of these discs having

been prepared, a pair of brass tools of the form shown in the sketch

(Fig. 55), and of about the proper radius of curvature, are made.

One of these tools is used as a support for the glass discs.

Fig. 55.

A compass being set to scribe circles of the same diameter as the

glass discs, centre marks are made on the surface of the appropriate

tool, circles are drawn on this, and facets are filed or milled (for

which the spiral head of the milling machine is excellent). In the

case of concave supporting surfaces, i.e. in making concave lenses, I

apprehend filing would be difficult, and the facets would have to be

made by a rose cutter or mill; but if the discs are fairly round,

then, in fact, no facets are required.

The facets being ready, the glass discs are cemented to them by

centering cement, which may be used quite generally for small lenses.

When the cutting of facets has been omitted on a concave surface, the

best cement is hard pitch. The grinding tool is generally rather

larger than the nest of lenses. Coarse and fine grinding is

accomplished wholly on the lathe--the tool being rotated at a fair

speed (see infra), and the nest of lenses moved about by its handle so

as to grind all parts equally. It must, of course, be held anywhere

except "dead on," for then the part round the axis would not get

ground; this inoperative portion of the rotating tool must therefore

be allowed to distribute its incapable efforts evenly over the nest of

lenses.

Polishing is accomplished by means of the grinding tool, coated with

paper and rouge as before; or the tool may be coated with very thin

cloth and used with rouge as before--in this case the polishing goes

on fastest when the surface of the cloth is distinctly damp. In

working by this method, each grade of emery need only be applied from

five to ten minutes. The glass does not appear to get scratched when

the emery is changed, provided everything is well washed. A good

polish may be got in an hour. The lathe is run as for turning brass

of the same diameter as the tool.

One side of the lenses being thus prepared, they are reversed, and the

process gone through for the other side in a precisely similar manner.

[Footnote: Unless the radius of curvature is very short and the lenses

also convex, there is no necessity to recess the facets, provided hard

pitch is used as the cement. See note on hard pitch.] To save

trouble, it is usual, to make such lenses of equal curvature on both

faces; but of course this is a matter of taste.

Fig. 56.

For very common work, bits of good plate glass are employed, and the

manufacturer's surface treated as flat (Fig. 56). In this way

plano-convex lenses are easily and cheaply made. Finally the lenses

have to be centred, an essential operation in this case. This is

easily done by the reflection method--the edge being turned off by

the file and kerosene and the centering cement being used in making

the preliminary adjustment on the chuck. I presume a lens made in

this way is worth about a shilling, so that laboratory manufacture is

not very remunerative. Fig. 56 shows the method of mounting small

lenses for lathe grinding, when only one lens is required. The tool

is generally rotated in the lathe and the lens held against it.

§ 65. Preparing Small Mirrors for Galvanometers.

To get good mirrors for galvanometers, I have found the best plan is

to grind and polish a large number together, on a disc perhaps 8 or 10

inches in diameter. I was led to this after inspecting and rejecting

four ounces of microscope cover slips, a most wearisome process. That

regular cover slips should be few and far between is not unlikely,

seeing that they are made (by one eminent firm at least) simply by

"pot" blowing a huge thin bulb, and then smashing it on the floor and

selecting the fragments. As in the case of large mirrors, it is of

course only necessary to grind one side of the glass, theoretically at

all events. The objections to this course are:

(1) A silver surface cannot, in my experience, be polished externally

(on a minute object like a cover slip) to be anything like so bright

as the silver surface next the glass; and,

(2) if one side only is ground, it will be found that the little

mirror hopelessly loses its figure directly it is detached from the

support on which it has been worked. Consequently, I recommend that

these small mirrors should be ground and polished on both

sides--enough may be made at one operation to last for a very long time.

A slate back is prepared of the same radius of curvature as it is

desired to impart to the mirrors. Bits of thin sheet glass are then

ground circular as described in the last section and cemented to this

surface by the smallest quantity of clean archangel pitch, allowed to

cool slowly and even to rest for a day before the work is proceeded

with. The whole surface is then ground and polished as before.

The mirrors are now reversed, when they ought to nearly fit the tool

(assuming that flats are being made, and the fellow tool in all other

cases), and are recemented by pitch to the appropriate backing ground,

and polished. If very excellent results are required, these processes

may be preceded by a preliminary rough grinding of one surface, so

that the little discs will "sit" exactly on the tool surface, and not

run the risk of being strained by capillary forces in the pitch. We

have always found this necessary for really good results.

On removing such mirrors from the backing, they generally, more or

less lose their figure, becoming (in general fairly uniformly) more

concave or convex. About 5 per cent of the mirrors thus prepared will

be found almost perfect if the work has been well done, and the rest

will probably be very fair, unless the diameter is very large as

compared with the thickness. The best way of grinding and polishing

such large surfaces (nests 10 inches in diameter) is on a grinding

machine, such as will be described below. The polishing is best done

by means of paper, as before described.

Having occasion to require hitherto unapproached lightness and optical

accuracy in such mirrors, I got my assistant to try making them of

fused quartz, slices being cut by a diamond wheel from a rod of that

material. Chips of natural quartz were also obtained from broken

"pebble" spectacles, and these were worked at the same time. The

resulting mirrors were certainly superior to the best we could make

from glass, but the labour of grinding was greater, and the labour of

polishing less, than in the latter case. The pebble fragments gave

practically as good mirrors as the fused slices. For the future it

will be better always to make galvanometer mirrors from quartz

crystals. These may be easily sliced, as will be described in § 74.

The slices are dressed on a grindstone according to instructions

already given for small lenses.

The silvering of these mirrors is a point of great importance. After

trying nearly every formula published, we have settled down to the

following.

A solution of pure crystallised nitrate of silver in distilled water

is made up to a strength of 125 grams of the salt per litre. This

forms the stock solution and is kept in a dark bottle.

Let the volume of silvering liquor required in any operation be

denoted by 4 v. The liquor is prepared as follows:

I. Measure out a volume v of the stock solution of silver nitrate,

and calculate the weight of salt which it contains; let this be w.

In another vessel dissolve pure Rochelle salt to the amount of 2.6 w,

and make up the solution to the volume v. These two solutions are to

be mixed together at a temperature of 55° C, the vessels with their

contents being heated to this temperature on the water bath. After

mixing the liquids the temperature is to be kept approximately

constant for five minutes, after which the liquor may be cooled. The

white precipitate which first forms will become gray or black and very

dense as the liquid cools. If it does not, the liquor must be

reheated to 55° C, and kept at that temperature for a few minutes and

then again allowed to cool. The solution is in good order when all

the precipitate is dense and gray or black and the liquor clear. The

blacker and denser the precipitate the better is the solution. The

liquor is decanted and filtered from the precipitate and brought up to

the volume 2 v by addition of some of the wash water.

II. Measure out a volume 0.118 v of the stock solution into a

separate vessel, and add to it a 5 per cent solution of ammonium

hydrate, with proper precautions, so that the precipitate at first

formed is all but redissolved after vigorous shaking. It is very

important that this condition should be exactly attained. Therefore

add the latter part of the ammonia very carefully. Make up the volume

to 2 v.

Mix the solutions I. and II. in a separate vessel and pour the

mixture into the depositing vessel. The surface to be silvered should

face downwards, and lie just beneath the free surface of the liquid.

Bubbles must of course be removed.

The silver deposit obtained in this manner is exceedingly white and,

bright on the surface next to the glass, but the back is mat and

requires polishing.

The detail of the process described above was worked out in my

laboratory by Mr. A. Pollock, to whom my thanks are due.

This process gives good deposits when the solutions are freshly

prepared, but the ammonia solution will not keep; The surfaces to be

silvered require to be absolutely clean. The process is assisted by a

summer temperature, say 70° Fahr, and possibly by the action of

light. Six or seven hours at least are required for a good deposit; a

good plan is to leave the mirrors in the bath all night. On removal

from the bath the mirrors require to be well washed, and allowed to

dry thoroughly in sun heat for several hours before they are touched.

Care should be taken not to pull the mirrors out of shape when they

are mounted for the bath. A single drop of varnish or paint (a mere

speck) on the centre will suffice to hold them. The back of the

deposit requires to be varnished or painted as a rule to preserve the

silver. All paints and varnishes thus applied tend to spoil the

figure by expanding or contracting. On the whole, I think boiled

linseed oil and white or red lead--white or red paint in fact--is

less deleterious than other things I have tried. Shellac varnish is

the worst.

Of course, the best mirror can be easily spoiled by bad mounting. I

have tried a great number of methods and can recommend as fairly

successful the following:- A little pure white lead, i.e. bought as

pure as a chemical--not as a paint--is mixed with an equal quantity

of red lead and made into a paste with a little linseed oil. I say a

paste, not putty. A trace of this is then worked on to the back of

the mirror at the centre as nearly as may be, and to this is attached

the support. The only objection to this is that nearly a week is

required for the paste to set. If people must use shellac let it be

remembered that it will go on changing its shape for months after it

has cooled (whether it has been dissolved in alcohol or not).

§ 66. Preparation of Large Mirrors or Lenses for Telescopes.

So much has been written on this subject by astronomers, generally in

the English Mechanic and in the Philosophical Transactions for 1840,

that it might be thought nothing could be added. I will only say here

that the processes already described apply perfectly to this case; but

of course I only refer to silver on glass mirrors. For any size over

6 inches in diameter, the process of grinding and polishing by hand,

particularly the latter, will probably be found to involve too much

labour, and a machine will be required. A description of a

modification of Mr. Nasmyth's machine--as made by my assistant, Mr.

Cook--will be found below.

There is no difficulty in constructing or working such a machine, and

considered as an all round appliance, it possesses solid advantages

over the simple double pulley and crank arrangement, which, however,

from its simplicity deserves a note. Two pulleys, A and B, of about

18 inches diameter by 4 inches on the face, are arranged to rotate

about vertical axes, and belted together. The shaft of one of these

pulleys is driven by a belt in any convenient manner. Each pulley is

provided on its upper surface with a crank of adjustable length

carrying a vertical crank-pin.

Each crank-pin passes through a 3"X 2" wooden rod, say 3' 6" long, and

these rods are pinned together at their farther extremities, and this

pin carries the grinding or polishing tool, or rather engages loosely

with the back of this tool which lies below the rod. It is clear that

if the pulleys are of commensurable diameters, and are rigidly

connected--say by belting which neither stretches nor slips--the

polishing tool will describe a closed curve. If, however, the belt is

arranged to slip slightly, or if the pulleys are of incommensurable

diameters, the curve traced out by the grinding tool will be very

complex, and in the case of the ratio of the diameters being

incommensurable, will always remain open; for polishing purposes the

consummation to be wished.

Mirror surfaces are ground spherical, the reduction to parabolic form

being attained in the process of polishing. A very interesting

account of the practice of dealing with very large lenses will be

found in Nature, May 1886, or the Journal of the Society of Arts, same

date (I presume), by Sir Howard Grubb. The author considers that the

final adjustment of surfaces by "figuring"--of which more anon--is

an art which cannot be learned by inspection, any more than a man

could learn to paint by watching an artist. This is, no doubt, the

case to some extent; still, a person wishing to learn how to figure a

lens could not do better than take Sir Howard at his word, and spend a

month at his works. Meanwhile the following remarks must suffice; it

is not likely that anybody to whom these notes will be of service

would embark on such large work as is contemplated by Sir Howard

Grubb.

Fig. 57.

Description of Polishing Machine. Power is applied through belting to

the speed cone A. By means of a bevel pinion rotation is communicated

to the wheel D, which is of solid metal and carries a T-slot, C. A

pedestal forming a crank-pin can be clamped so as to have any desired

radius of motion by the screw E. A train of wheels E F G H K

(ordinary cast lathe change wheels) communicate any desired ratio of

motion to the tool-holder, which simply consists of two pins

projecting vertically downwards from the spokes of wheel K.

These pins form a fork, and each prong engages in a corresponding hole

in the back of the slate-grinding tool (not shown in figure). The

connection with the tool is purposely loose. The wheel E, of course,

cannot rotate about the crank-pin D. Provision for changing the ratio

of tool rotation is achieved by mounting the wheels composing the

train on pins capable of sliding along a long slot in the bar

supporting them. The farther end of this bar is caused to oscillate

to and fro very slowly by means of an additional crank-pin S and

crank-shaft, the projecting face of the bed-plate W being placed

so as to allow V to slide about easily and smoothly.

Motion is communicated to this part of the system by means of

gears at 0 and P, and a belt working from P to Q.

Thus the vertical shaft R is set in motion and

communicates by gears with S. A pulley placed on the axle of the

wheel carrying the crank-pin S gives a slow rotation to the work which

is mounted on the table M. A small but important feature is the tray L

below the gear K. This prevents dirt falling from the teeth of the

wheel on to the work. The motion of S is of course very much less

than of B--say 100 times less. The work can be conveniently adjusted

as to height by means of the screw N.

The machine must be on a steady foundation, and in a place as free

from dust as possible. Though it looks complicated it is quite

straight-forward to build and to operate.

It is explained in Lord Rayleigh's article on Optics in the

Encyclopaedia Britannica that a very minute change in the form of the

curvature of the surface of a lens will make a large difference in the

spherical aberration. This is to be expected, seeing that spherical

aberration is a phenomenon of a differential sort, i.e. a measure of

the difference between the curvature actually attained, and the

theoretical curvature at each point of the lens, for given positions

of point and image. Sir H. Grubb gives an illustration of the

minuteness of the abrasion required in passing from a curve of one

sort to a curve of another, say from a spherical to a parabolic curve,

consequently the process of figuring by the slow action of a polishing

tool becomes quite intelligible. In making a large mirror or lens all

the processes hitherto described under grinding and polishing, etc,

have to be gone through and in the manner described, and when all this

is accomplished the final process of correcting to test commences.

This process is called figuring.

§ 67. Of the actual operation of this process I have no personal

knowledge, and the following brief notes are drawn from the article by

Sir H. Grubb, from my assistant's (Mr. Cook) experience, and from a

small work On the Adjustment and Testing of Telescopic Objectives, by

T. Cook and Sons, Buckingham Works, York (printed by Ben Johnson and

Co, Micklegate, York). This work has excellent photographs of the

interference rings of star images corresponding to various defects.

It must be understood that the following is a mere sketch. The art

will probably hardly ever be required in laboratory practice, and

those who wish to construct large telescopes should not be above

looking up the references.

The process is naturally divided for treatment into two parts.

(1) The detection of errors, and the cause of these errors.

(2) The application of a remedy.

(1) A lens, being mounted with its final adjustments, is turned on to

a star, which must not be too bright, and should be fairly overhead.

The following appearances may be noted:-

A. In focus, the star appears as a small disc with one or two rings

round it; inside and outside of the focus the rings increase in

number, are round, concentric with the disc, and the bright and dark

rings are apparently equally wide. The appearance inside the focus

exactly resembles that outside when allowance is made for chromatic

effects. Conclusion: objective good, and correctly mounted.

B. The rings round the star in focus are not circular, nor is the

star at the centre of the system. In bad cases the fringes are seen at

one side only. Effects exaggerated outside and inside the focus.

Conclusion: the lens is astigmatic, or the objective is not adjusted

to be co-axial with the eyepiece.

C. When in focus the central disc is surrounded by an intermittent

diffraction pattern, i.e. for instance the system of rings may appear

along, and near, three or more radii. If these shift when the points

of support of the lens are shifted, flexure may be suspected.

D. On observing inside and outside the focus, the rings are not

equally bright and dark. This may be due to uncorrected spherical

aberration, particularly to a fault known as "zonal aberration," where

different zones of the lens have different foci, but each zone has a

definite focus.

E. Irregular diffraction fringes point to bad annealing of the glass.

This may be checked by an examination of the lens in polarised light.

F. If the disc appear blurred and coloured, however the focus be

adjusted, incomplete correction for chromatic aberration is inferred.

If in addition the colouring is unsymmetrical (in an extreme case the

star disc is drawn out to a coloured band), want of centering is to be

inferred. This will also show itself by the interference fringes

having the characteristics described in C.

(2) The following steps may be taken in applying a remedy:

A. The adjusting screws of the cell mounting the object glass may

be worked until the best result is attained; this requires great

care and patience. Any errors left over are to be attributed to

other causes than the want of collinearity of the axes of object

glass and eyepiece.

B. Astigmatism is detected by rotating the object glass or object

glass cell. If the oval fringes still persist and the longer axis

follows the lens, astigmatism may be inferred. Similarly, by rotating

one lens on the other, astigmatism, or want of centering (quite a

different thing) may be localised to the lens.

C. The presence of flexure may be confirmed by altering the position

of the points of support with respect to the eyepiece, the lens

maintaining its original position. The addition of more points of

support will in general reduce the ill effects. How to get rid of

them I do not know; they are only serious with large lenses.

D. Spherical aberration may be located by using stops and zonal

screens, and observing the effect on the image. Sir H. Grubb

determines whether any point on the lens requires to be raised or

lowered, by touching the glass at that point with a warm hand or

cooling it by ether. The effects so produced are the differential

results of the change of figure and of refractive index. By observing

the effect of the heating or cooling of any part, the operator will

know whether to raise or lower that part, provided that by a suitable

preliminary experiment he has determined the relation between the

effect produced by the change of figure, and that due to the

temperature variation of the refractive index. In general it is

sufficient to consider the change of shape only and neglect the change

in refractive power.

E. Marked astigmatism has never been noticed by me, but I should

think that the whole lens surface would require to be repolished or

perhaps reground in this case.

F. To decide in which surface faults exist is not easy. By placing a

film of oil between the two surfaces nearly in contact these may be

easily examined. Thus a mixture of nut and almond oil of the right

proportion, to be found by trial, for the temperature, will have the

same refractive index as the crown glass, and will consequently reduce

any errors of figure in the interior crown surface, if properly

applied between the surfaces. Similarly the interior of the flint

surface may have its imperfections greatly reduced in effect by using

almond oil alone, or mixed with bisulphide of carbon. The outer

surfaces, I presume, must be examined by warming or cooling over

suitable areas or zones.

The defects being detected, a matter requiring a great deal of skill

and experience according to Sir H. Grubb, the next step is to remedy

them; and the remedial measures as applied to the glass constitute the

process of figuring. There are two ways of correcting local defects,

one by means of small paper or pitch covered tools, which according to

Sir H. Grubb is dangerous, and according to the experience of Mr.

Cook, and I think of many French opticians, safe and advantageous.

Pitch polishing tools are generally used for figuring. They are made

by covering a slate backing with squares of pitch. The backing is

floated with pitch say one-eighth of an inch thick. This is then

scored into squares by a hot iron rod. The tool, while slightly warm,

is laid upon the lens surface, previously slightly smeared with dilute

glycerine, until the pitch takes the figure of the glass. The

polishing material is rouge and water. Small tools are applied

locally, and probably can only be so applied with advantage for grave

defects.

The other method is longer and probably safer. It consists in

furnishing the polishing tool with squares of pitch as before. These

being slightly warm, the lens is placed upon them so that they will

flow to the exact figure also as before. I presume that the lens is

to be slightly smeared with glycerine, or some equivalent, to keep the

pitch from sticking. The squares are most thickly distributed where

the abrasion is most required, i.e. less pitch is melted out by the

iron rod. This may be supplemented by taking advantage of differences

of hardness of pitch, making some squares out of harder, others out of

softer pitch. The aim is to produce a polishing tool which will

polish unequally so as to remove the glass chiefly from predetermined

parts of the lens surface. The tool is worked over the surface of the

lens by the polishing machine, and part of the art consists in

adjusting the strokes to assist in the production of the local

variations required.

A source of difficulty and danger lies in the fact that the pitch

squares are rarely of the same hardness, so that some abrade the glass

more rapidly than others. This is particularly likely to occur if the

pitch has been overheated. [Footnote: When pitch is heated till it

evolves bubbles of gas its hardness increases with the duration of the

process.] The reader must be good enough to regard these remarks as

of the barest possible kind, and not intended to convey more than a

general idea of the nature of the process of figuring.

§ 68. A few remarks on cleaning lenses will fittingly close this part

of the subject. There is no need to go beyond the following

instructions given by Mr. Brashear in Popular Astronomy, 1894, which

are reproduced here verbatim.

"The writer does not advise the use of either fine chamois skin,

tissue paper, or an old soft silk handkerchief, nor any other such

material to wipe the lenses, as is usually advised. It is not,

however, these wiping materials that do the mischief, but the dust

particles on the lenses, many of them perhaps of a silicious nature,

which are always harder than optical glass, and as these particles

attach themselves to the wiping material they cut microscopic or

greater scratches on the surfaces of the objective in the process of

wiping.

"I write this article with the hope of helping to solve this

apparently difficult problem, but which in reality is a very simple

one.

"Let us commence by taking the object glass out of its cell. Take out

the screws that hold the ring in place, and lift out the ring.

Placing the fingers of both hands so as to grasp the objective on

opposite sides, reverse the cell, and with the thumbs gently press the

objective squarely out of the cell on to a book, block of wood, or

anything a little less in diameter than the objective, which has had a

cushion of muslin or any soft substance laid upon it. One person can

thus handle any objective up to 12 inches in diameter.

"Before separating the lenses it should be carefully noted how they

were put together with relation to the cell, and to one another, and

if they art not marked they should be marked on the edges

conspicuously with a hard lead pencil, so that when separated they may

be put together in the same way, and placed in the same relation to

the cell. With only ordinary precaution this should be an easy

matter.

"Setting the objective on edge the two lenses may be readily

separated.

"And now as to the cleaning of the lenses. I have, on rare occasions,

found the inner surfaces of an object glass covered with a curious

film, not caused directly by moisture but by the apparent oxidation of

the tin-foil used to keep the lenses apart. "A year or more ago a

7-inch objective made by Mr. Clark was brought to me to clean. It had

evidently been sadly neglected. The inside of the lenses were covered

with such a film as I have mentioned, and I feared the glass was

ruined. When taken apart it was found that the tin-foil had oxidised

totally and had distributed itself all over the inner surfaces. I

feared the result, but was delighted to find that nitric acid and a

tuft of absorbent cotton cut all the deposit off, leaving no stains

after having passed through a subsequent washing with soap and water.

"I mention this as others may have a similar case to deal with.

"For the ordinary cleaning of an objective let a suitable sized

vessel, always a wooden one, be thoroughly cleaned with soap and

water, then half filled with clean water about the same temperature as

the glass. Slight differences of temperature are of no moment. Great

differences are dangerous in large objectives.

"I usually put a teaspoonful of ammonia in half a pail of water, and

it is well to let a piece of washed 'cheese cloth' lie in the pail, as

then there is no danger if the lens slips away from the hand, and, by

the way, every observatory, indeed every amateur owning a telescope,

should have plenty of 'cheese cloth' handy. It is cheap (about 3 cts.

per yard) and is superior for wiping purposes to any 'old soft silk

handkerchief,' chamois skin, etc. Before using it have it thoroughly

washed with soap and water, then rinsed in clean water, dried and laid

away in a box or other place where it can be kept clean. When you use

a piece to clean an objective throw it away, it is so cheap you can

afford to do so.

"If the lenses are very dirty or 'dusty,' a tuft of cotton or a

camel's-hair brush may be used to brush off the loose material before

placing the lenses in the water, but no pressure other than the weight

of the cotton or brush should be used. The writer prefers to use the

palms of the hand with plenty of good soap on them to rub the

surfaces, although the cheese cloth and the soap answers nicely, and

there seems to be absolutely no danger of scratching when using the

hands or the cheese cloth when plenty of water is used; indeed when I

wish to wipe off the front surface of an objective in use, and the

lens cannot well be taken out, I first dust off the gross particles

and then use the cheese cloth with soap and water, and having gone

over the surface gently with one piece of cloth, throw it away and

take another, perhaps a third one, and then when the dirt is, as it

were, all lifted up from the surface, a piece of dry cheese cloth will

finish the work, leaving a clean brilliant surface, and no scratches

of any kind.

"In washing large objectives in water I generally use a 'tub' and

stand the lenses on their edge. When thoroughly washed they are taken

out and laid on a bundle of cheese cloth and several pieces of the

same used to dry them.

"I think it best not to leave them to drain dry; better take up all

moisture with the cloth, and vigorous rubbing will do no harm if the

surfaces have no abrading material on them. I have yet to injure a

glass cleaned in this way.

"This process may seem a rather long and tedious one, but it is not so

in practice, and it pays.

"In some places objectives must be frequently cleaned, not only

because they become covered with an adherent dust, but because that

dust produces so much diffused light in the field as to ruin some

kinds of telescope work. Mr. Hale of the Kenwood Observatory tells me

he cannot do any good prominence photography unless his objective has

a clean surface; indeed every observer of faint objects or delicate

planetary markings knows full well the value of a dark field free from

diffused light. The object-glass maker uses his best efforts to

produce the most perfect polish on his lenses, aside from the accuracy

of the curves, both for high light value and freedom from diffused

light in the field, and if the surfaces are allowed to become covered

with dust, his good work counts for little.

"If only the front surface needs cleaning, the method of cleaning

with cheese cloth, soap and water, as described above, answers very

well, but always throw away the first and, if necessary, the second

cloth, then wipe dry with a third or fourth cloth; but if the

surfaces all need cleaning I know of no better method than that of

taking the objective out of its cell, always using abundance of soap

and water, and keep in a good humor."

§ 69. The Preparation of Flat Surfaces of Rock Salt.

The preliminary grinding is accomplished as in the case of glass,

except that it goes on vastly faster. The polishing process is the

only part of the operation which presents any difficulty. The

following is an extract from a paper on the subject, by Mr. J. A.

Brashear, Pittsburg, Pa, U.S.A, from the Proceedings of the American

Association for the Advancement of Science, 1885. Practically the

same method was shown me by Mr. Cook some years earlier, so that I can

endorse all that Mr. Brashear says, with the following exceptions. We

consider that for small salt surfaces the pitch is better scored into

squares than provided with the holes recommended by Mr. Brashear.

Mr. Brashear's instructions are as follows. After alluding to the

difficulty of drying the polished salt surface--which is of course

wet--Mr. Brashear says:-

"Happily I have no trouble in this respect now, and as my method is

easily carried out by any physicist who desires to work with rock salt

surfaces, it gives me pleasure to explain it. For polishing a prism I

make an ordinary pitch bed of about two and one-half or three times

the area of the surface of the prism to be polished. While the pitch

is still warm I press upon it any approximately flat surface, such as

a piece of ordinary plate glass. The pitch bed is then cooled by a

stream of water, and conical holes are then drilled in the pitch with

an ordinary counter sink bit, say one-quarter of an inch in diameter,

and at intervals of half an inch over the entire surface. This is

done to relieve the atmospheric pressure in the final work. The upper

surface of the pitch is now very slightly warmed and a true plane

surface (usually a glass one, prepared by grinding and polishing three

surfaces in the ordinary way, previously wetted) is pressed upon it

until the pitch surface becomes an approximately true plane itself.

Fortunately, moderately hard pitch retains its figure quite

persistently through short periods and small changes of temperature,

and it always pays to spend a little time in the preparation of the

pitch bed.

"The polisher being now ready, a very small quantity of rouge and

water is taken upon a fine sponge and equally distributed over its

surface. The previously ground and fined salt surface (this work is

done the same as in glass working) is now placed upon the polisher and

motion instantly set up in diametral strokes. I usually walk around

the polisher while working a surface. It is well to note that motion

must be constant, for a moment's rest is fatal to good results, for

the reason that the surface is quickly eaten away, and irregularly so,

owing to the holes that are in the pitch bed. Now comes the most

important part of this method. After a few minutes' work the moisture

will begin to evaporate quite rapidly. No new application of water is

to be made, but a careful watch must be kept upon the pitch bed, and

as the last vestige of moisture disappears the prism is to be slipped

off the polisher in a perfectly horizontal direction, and if the work

has been well done, a clean, bright, and dry surface is the result.

The surface is now tested by the well-known method of interference

from a perfect glass test plate (see Fig. 178).

"If an error of concavity presents itself the process of polishing is

gone over again, using short diametral strokes. If the error is one

of convexity, the polishing strokes are to be made along the chords,

extending over the edge of the polisher. The one essential feature of

this method is the fact that the surface is wiped dry in the final

strokes, thus getting rid of the one great difficulty of pitch

polishing, a method undoubtedly far superior to that of polishing on

broadcloth. If in the final strokes the surface is not quite cleaned

I usually breathe upon the pitch bed, and thus by condensation place

enough moisture upon it to give a few more strokes, finishing just the

same as before. In ten minutes I have polished prisms of rock salt in

this manner that have not only shown the D line double, but Professor

Langley has informed me that his assistant, Mr. Keeler (J. E.), has

seen the nickel line clearly between the D lines. This speaks for the

superiority of the surfaces over those polished on broadcloth.

"In polishing prisms I prefer to work them on top of the polisher, as

they can be easily held, but as it is difficult to hold lenses or

planes in this way without injuring the surfaces, I usually support

them in a block of soft wood, turned so as to touch only at their

edges, and work the polisher over them. Though it takes considerable

practice to succeed at first, the results are so good that it well

repays the few hours' work it requires to master the few difficulties

it presents."

Fig. 58.

§ 70. Casting Specula for Mirrors.

According to Sir H. Grubb (loc. cit.) the best alloy is made of four

atoms of copper and one of tin; this gives by weight,

copper 252, tin 117.8.

The copper is melted first in a plumbago crucible; the tin is added

gradually. Of course, in the process of melting, even though a little

fine charcoal be sprinkled over the copper, some loss of that metal

will occur from oxidation. It is convenient in practice, therefore to

reserve a portion of the tin and test the contents of the crucible by

lifting a little of the alloy out and examining it.

The following indications may be noted: When the copper is in excess

the tint of the alloy is slightly red, and the structure, as shown at

a fractured surface, is coarsely crystalline. As the proper

proportions are more nearly attained, the crystalline structure

becomes finer, the colour whiter, and the crystals brighter. The

alloy is ready for use when the maximum brightness is attained and the

grain is fine.

If too much tin be added, the lustre diminishes. The correct

proportion is, therefore, attained when a further small addition of

tin produces no apparent increase of brightness or fineness of grain.

About three-quarters of the tin may be added at first, and the other

quarter added with testing as described. The alloy is allowed to cool

until on skimming the surface the metal appears bright and remains so

without losing its lustre by oxidation for a sensible time; it will

still be quite red-hot.

Fig. 59. Fig. 60.

As the speculum alloy is too difficult to work with ordinary tools, it

is best to cast the speculum of exactly the required shape and size.

This is done by means of a ring of iron turned inside (and out) and on

one edge. This ring is laid on a plate of figured iron, and before

the metal is poured the plate (G) (Figs 59 and 61) is heated to, say,

300° C. In order to avoid the presence of oxide as far as possible,

the following arrangements for pouring are made. A portion of the

lower surface of the ring is removed by radial filing until a notch

equal to, say, one-twentieth of the whole circumference is produced.

This is cut to an axial depth of, say, half an inch.

A bar of iron is then dovetailed loosely into the notch (Fig. 60, B),

so that it will rest on the iron plate, and half fill the notch. The

aperture thus left forms the port of ingress for the hot metal (see

Fig. 61, M). A bit of sheet iron is attached to the upper surface of

the ring, and lies as a sort of flap, shaped like a deep shovel,

against the outside of the ring overhanging the port (Figs. 59 and 61

at F). This flap does not quite reach the iron plate, and its sides

are bent so as to be in contact with the ring. A portion of a smaller

ring is then applied in such a manner as to form a pouring lip or pool

on the outside of the main ring at E, and the metal can only get into

the main ring by passing under the edge of the flap and up through the

port. This forms an efficient skimming arrangement. The process of

casting is carried out by pouring steadily into the lip.

To avoid air bubbles it is convenient to cause the metal to spread

slowly over the chill, and Mr. Nasmyth's method of accomplishing this

is shown in the figure (61). The chill rests on three pins, A B C

(Figs. 59 and 61). Before pouring begins the chill is tilted up off

C by means of the counterpoise D, which is insufficient to tilt it

after the speculum is poured. It is important that the chill should

be horizontal at the close of the operation, in order that the

speculum may be of even thickness throughout. This is noted by means

of levels placed on the ring (at K for instance).

Fig. 61.

This apparatus may appear unnecessarily complex, but it is worth while

to set it up, for it makes the operation of casting a speculum fairly

certain. If the metal is at the right temperature it will form a

uniformly liquid disc inside the ring. The mass sets almost directly,

and as soon as this occurs it is pushed to the edge of the plate and

the metal in the lip broken off by a smart upward tap with a hammer.

The dovetailed bit of iron is knocked downwards and falls off, and the

ring may then be lifted clear of the casting. The object of the

dovetail will now be understood, for without it there is great risk of

breaking into the speculum in knocking the "tail" off.

A box of quite dry sawdust is prepared in readiness for the process of

annealing before the speculum is cast. The box must be a sound wooden

or metal box, and must be approximately air-tight. For a speculum a

foot in diameter the box must measure at least 3 feet both ways in

plan, and be 2 feet 6 inches deep. Half the sawdust is in the box and

is well pressed down so as to half fill it. The other half must be

conveniently ready to hand. As soon as possible after casting, the

speculum is thrown into the box, covered over with the sawdust, and

the lid is put on.

The object in having the box nearly air-tight is to avoid

air-currents, which would increase the rate of cooling. A speculum a

foot in diameter may conveniently take about three days to anneal, and

should be sensibly warm when the box is opened on the fourth day. For

larger sizes longer times will be required. We will say that the

sawdust thickness on each side must be proportional to the dimensions

of the speculum, or may even increase faster with advantage if time is

of no moment.

The process of annealing may be considered successful if the disc does

not fly to pieces in working; it is to be worked on the chilled side.

The object of giving the chill the approximate counterpart form will

now appear; it saves some rough grinding, and causes the finished

surface to be more homogeneous than it would be if the centre were

sunk by grinding through the chilled surface.

In 1889 I learned from Mr. Schneider, Professor Row-land's assistant

at Baltimore, that in casting specula for concave gratings a good deal

of trouble had been saved by carrying out the operation in an

atmosphere consisting mostly of coal gas. It was claimed that in this

way the presence of specks of oxide was avoided. I did not see the

process in operation, but the results attained are known and admired

by all experimenters.

§ 71. Grinding and polishing Specula.

The rough grinding is accomplished by means of a lead tool and coarse

emery; the size of grain may be such as will pass a sieve of 60

threads to the inch. The process of grinding is quite similar to that

previously described, but it goes on comparatively quickly. The rough

grinding is checked by the spherometer, and is interrupted when that

instrument gives accordant and correct measurements all over the

surface.

The fine grinding may be proceeded with by means of a glass-faced tool

as before described, or the labour may be reduced in the following

manner. A slate tool, which must be free from green spots (a source

of uneven hardness), is prepared, and this is brought nearly to the

curvature of the roughly ground speculum, by turning or otherwise. It

is finished on the speculum itself with a little flour of emery. The

fine grinding is then carried on by means of slate dust and water, the

slate tool being the grinder. The tool is, of course, scored into

squares on the surface.

If the casting process has been carried out successfully, the rough

grinding may take, say six hours, and the fine grinding say thirty

hours for a disc a foot in diameter. The greatest source of trouble

is want of homogeneity in the casting, as evidenced by blowholes, etc.

In general, the shortest way is to discard the disc and start afresh

if there is any serious want of perfection in the continuity or

homogeneity of the metal.

Fig. 62.

The finely ground surface must, of course, be apparently correct in so

far as a spherometer (with 3 inches between the legs for a disc 1 foot

in diameter) will show. Polishing and figuring are carried out

simultaneously. Half an hour's polishing with a slate-backed pitch

tool and rouge and water will enable an optical test to be made. The

most convenient test is that of Foucault, a simple appliance for the

purpose being shown in the figure (62). It essentially consists of a

small lamp surrounded by an opaque chimney (A) through which a minute

aperture (pin-hole) is made. A small lens may be used, of very great

curvature, or even a transparent marble to throw an image of the flame

on the pin-hole.

A screen (B) is placed close to the source, and is provided with a

rocking or tilting motion (C) in its own plane. The source and screen

are partly independent, and each is provided with a fine adjustment

which serves to place it in position near the centre of curvature.

The screen is so close to the pin-hole in fact that both the source

and a point on the edge of the screen may be said to be at the centre

of curvature of the mirror. The mirror is temporarily mounted so as

to have its axis horizontal, in a cellar or other place of uniform

temperature.

The final focussing to the centre of curvature is made by the fine

adjustment screws; the image may be received on a bit of paper placed

on the screen and overlapping the edge nearest the source. The screws

are worked till the image has its smallest dimension and is bisected

by the edge of the screen. The test consists in observing the

appearance of the mirror surface while the screen is tilted to cut off

the light, as seen by an eye placed at the edge of the screen, a

peephole or eye lens being provided to facilitate placing the eye in a

correct position. The screen screws are worked so as to gradually cut

off the light, and the observer notes the appearance of the mirror

surface. If the curves are perfect and spherical, the transition from

complete illumination to darkness will be abrupt, and no part of the

mirror will remain illuminated after the rest.

For astronomical purposes a parabolic mirror is required. In this

case the disc may be partially screened by zonal screens, and the

position of the image for different zones noted; the correctness or

otherwise of the curvature may then be ascertained by calculation. A

shorter way is to place the source just outside the focus, to be found

by trial, and then, moving the extinction screen (now a separate

appliance) to, say, five times the radius of curvature away, where the

image should now appear, the suddenness of extinction may be

investigated. This, of course, involves a corresponding modification

of the apparatus.

Whether the tests indicate that a deepening of the Centre, i.e.

increase of the curvature, or a flattening of the edges is required,

at least two remedial processes are available. The "chisel and

mallet" method of altering the size of the pitch, squares of the

polisher may be employed, or paper or small pitch tools may be used to

deepen the centre. The "chisel and mallet" method merely consists in

removing pitch squares from a uniformly divided tool surface by means

of the instruments mentioned. This removal is effected at those

points at which the abrasion requires to be reduced.

When some practice is attained, I understand that it is usual to try

for a parabolic form at once, as soon as the polishing commences.

This is done by dividing the pitch surface by V-shaped grooves, the

sides of the grooves being radii of the circular surface, so that the

central parts of the mirror get most of the polishing action. If

paper tools are used they must not be allowed much overhang, or the

edges of the mirror betray the effects of paper elasticity. Most

operators "sink" the middle, but the late Mr. Lassell, a most

accomplished worker, always attained the parabolic form by reducing

the curvature of the edges of a spherical mirror.

§ 72. Preparation of Flat Surfaces.

As Sir H. Grubb has pointed out, this operation only differs from

those previously described in that an additional condition has to be

satisfied. This condition refers to the mean curvature, which must be

exact (in the case of flats it is of course zero) to a degree which is

quite unnecessary in the manufacture of mirrors or lenses.

A little consideration will show that to get a surface flat the most

straightforward method is to carry out the necessary and sufficient

condition for three surfaces to fit each other impartially. If they

each fit each other, they must clearly all be flat. To carry out the

process of producing a flat surface, therefore, two tools are made,

and the glass or speculum is ground first on one and then on the

other, the tools being kept "in fit" by occasional mutual grinding.

The grinding and polishing go on as usual. If paper is employed, care

must be taken that the polisher is about the same size as the object

to be polished.

There is a slight tendency to polish most at the edges; but if the

sweeps are of the right shape and size, this may be corrected

approximately. The best surfaces which have come under my notice are

those prepared as "test surfaces" by Mr. Brashear of Alleghany, Pa,

U.S.A. These I believe to be pitch polished. A pitch bed is

prepared, I presume, in a manner similar to that described for

rocksalt surfaces; but the working of the glass is an immense art, and

one which I believe--if one may judge by results--is only known to

Mr. Brashear.

In general, the effect of polishing will be to produce a convex or

concave surface, quite good enough for most purposes, but distinctly

faulty when tested by the interference fringes produced with the aid

of the test plate. The following information therefore--which I draw

from Mr. 'Cook--will not enable a student to emulate Mr. Brashear,

but will undoubtedly help him to get a very much better surface than

he usually buys at a high price, as exhibited on a spectroscope prism.

The only difference between this process and the one described for

polishing lenses, lies in the fact that the rouge is put into the

paper surface while the latter is wet with a dilute gum "mucilage."

It is of course assumed that the object and the two tools have been

finely ground and fit each other impartially. The paper is rubbed

over with rouge and weak gum water. The tool, when dry, is applied to

the flat ground surface (of the object), and is scraped with the

three-cornered file chisel as formerly described. This process must

be very carefully carried out. The paper must be of the quality

mentioned, or may even be thinner and harder. The cross strokes

should be more employed than in the case of the curved surfaces.

A good deal will depend on the method employed for supporting the

work; it is in general better to support the tool, which may have a

slate backing of any desired thickness, whereby the difficulty

resulting from strains is reduced. The work must be mounted in such a

way as to minimise the effect of changes of temperature. If a pitch

bed is selected, Mr. Brashear's instructions for rock salt may be

followed, with, of course, the obvious necessary modifications. See

also next section.

§ 73. Polishing Flat Surfaces on Glass or on Speculum Metal.

The above process may be employed for speculum metal, or pitch may be

used. In the latter case a fresh tool must be prepared every hour or

so, because the metal begins to strip and leave bits on the polisher;

this causes a certain amount of scratching to take place. As against

this disadvantage, the process of polishing, in so far as the state of

the surface is concerned, need not take an hour if the fine grinding

has been well done.

For the finest work changes of temperature, as in the case of glass,

cause a good deal of trouble, and the operator must try to arrange his

method of holding the object so as to give rise to the least possible

communication of heat from the hand.

The partial elasticity of paper, which is its defect as a polishing

backing, is, I believe, partly counterbalanced by the difficulty of

forming with pitch an exact counterpart tool without introducing a

serious rise of temperature (i.e. warming the pitch). The rate of

subsidence of the latter is very slow at temperatures where it is hard

enough to work reliably as a polisher.

A student interested in the matter of flat surfaces will do well to

read an account of Lord Rayleigh's work on the subject, Nature, vol.

xlviii, 1893, pp. 212, 526 (or B. A. Reports, 1893). In the first

of these communications Lord Rayleigh describes the method of using

test plates, and shows how to obtain the interference fringes in the

clearest manner.

For the ordinary optician a dark room and a soda flame afford all

requisite information; and if a person succeeds in making three glass

discs, say 6 inches in diameter, so flat that, when superposed in any

manner, the interference fringes are parallel and equidistant, even to

the roughest observation, he has nothing to learn from any book ever

written on glass polishing. Lord Rayleigh has also shown how to use

the free clean surface of water as a natural test plate.

Since the above was written the following details of his exact course

of procedure have been sent to me by Mr. Brashear, and I hereby tender

my thanks:-

"It really takes years to know just what to do when you reach that

point where another touch either gives you the most perfect results

attainable, or ruins the work you have already done. It has taken us

a long time to find out how to make a flat surface, and when we were

called upon to make the twenty-eight plane and parallel surfaces for

the investigation of the value of the metre of the international

standard, every one of which required an accuracy of one-twentieth of

a wave length, we had a difficult task to perform. However, it was

found that every surface had the desired accuracy, and some of them

went far beyond it.

It is an advantage in making flat surfaces to make more than one at a

time; it is better to make at least three, and in fact we always grind

and 'fine' three together. In making speculum plates we get up ten or

twelve at once on the lead lap. These speculum plates we can test as

we go on by means of our test plane until we get them nearly flat. In

polishing them we first make quite a hard polisher, forming it on a

large test plane that is very nearly correct. We then polish a while

on one surface and test it, then on a second and test it, and after a

while we accumulate plates that are slightly concave and slightly

convex. By working upon these alternately with the same polisher, we

finally get our polisher into such shape that it approximates more and

more to a flat surface, and with extreme care and slow procedure we

finally attain the results desired.

All our flats are polished on a machine which has but little virtue in

itself, unmixed with brains. Any machine giving a straight

diametrical stroke will answer the purpose. The glass should be

mounted so as to be perfectly free to move in every direction--that

is to say, perfectly unconstrained. We mount all our flats on a piece

of body Brussels carpet, so that every individual part of the woof

acts as a yielding spring. The flats are held in place by wooden

clamps at the edges, which never touch, but allow the bits of glass or

metal to move slowly around if they are circular; if they are

rectangular we allow them to tumble about as they please within the

frame holding them.

For making speculum metal plates either plane or concave we use

polishers so hard that they scratch the metal all over the surface

with fine microscopic scratches. We always work for figure, and when

we get a hard polisher that is in proper shape, we can do ever so many

surfaces with it if the environments of temperature are all right. If

we have fifty speculum flats to make, and we recently made three times

that number, we get them all ready and of accurate surface with the

hard polisher. Then we prepare a very soft polisher, easily indented

when cold with the thumb nail. A drop of rouge and about three drops

of water are put on the plate, and with the soft polisher about one

minute suffices to clean up all the scratches and leave a beautiful

black polish on the metal. This final touch is given by hand; if we

do not get the polish in a few minutes the surface is generally ruined

for shape, and we have to resort to the hard polisher again.

I assure you that nothing but patience and perseverance will master

the difficulty that one has to encounter, but with these two elements

'you are bound to get there.'"

CHAPTER III

MISCELLANEOUS PROCESSES

§ 74. Coating Glass with Aluminium and Soldering Aluminium.

A process of coating glass with aluminium has been lately discovered,

which, if I mistake not, may be of immense service in special cases

where a strongly adherent deposit is required. My attention was first

attracted to the matter by an article in the Archives des Sciences

physiques et naturelles de Genève, 1894, by M. Margot. It appears

that clean aluminium used as a pencil will leave a mark on clean damp

glass. If, instead of a pencil, a small wheel of aluminium--say as

big as a halfpenny and three times as thick--is rotated on the lathe,

and a piece of glass pressed against it, the aluminium will form an

adherent, though not very continuous coating on the glass.

Working with a disc of the size described rotating about as fast as

for brass-turning, I covered about two square inches of glass surface

in about five minutes. The deposit was of very uneven thickness, but

was nearly all thick enough to be sensibly opaque. By burnishing the

brilliance is improved (I used an agate burnisher and oil), but a

little of the aluminium is rubbed off. The fact that the burnisher

does not entirely remove it is a sign of the strength of the adherence

which exists between the aluminium and the glass. In making the

experiment, care must be taken to have the glass quite clean--or at

all events free from grease--in order to obtain the best results.

M. Margot has contributed further information to the Archives des

Sciences physiques et naturelles (February 1895). He finds that

adherence between aluminium and glass is promoted by dusting the glass

with powders, such as rouge. There is no doubt that a considerable

improvement is effected in this way; both rouge and alumina have in

my hands greatly increased the facility with which the aluminium is

deposited. M. Margot finds that zinc and magnesium resemble aluminium

in having properties of adherence to glass, and, what is more, carry

this property into their alloys with tin. Thus an alloy of zinc and

tin in the proportions of about 92 per cent tin and 8 per cent zinc

may be melted on absolutely clean glass, and will adhere strongly to

it if well rubbed by an asbestos crayon.

A happy inspiration was to try whether these alloys would, under

similar circumstances, adhere to aluminium itself, and a trial showed

that this was indeed the case, provided that both the aluminium and

alloy are scrupulously clean and free from oxide. In this way M.

Margot has solved the problem of soldering aluminium. I have satisfied

myself by trial of the perfect ease and absolute success of this

method. The alloy of zinc and tin in the proportions above mentioned

is formed at the lowest possible temperature by melting the

constituents together. It is then poured so as to form thin sticks.

The aluminium is carefully cleaned by rubbing with a cuttle bone, or

fine sand, and strong warm potash. It is then washed in water and

dried with a clean cloth. The aluminium is now held over a clean

flame and heated till it will melt the solder which is rubbed against

it. The solder sticks at once, especially if rubbed with another bit

of aluminium (an aluminium soldering bit) similarly coated. To solder

two bits of aluminium together it is only necessary to tin the bits by

this process and then sweat them together.

The same process applies perfectly to aluminium caused to adhere to

glass by the previously mentioned process, and enables strong soldered

contacts to be made to glass. In one case, while I was testing the

method, the adhesion was so strong that the solder on contracting

while cooling actually chipped the surface clean off the glass. In

order to get over this I have endeavoured to soften the solder by

mixing in a little of the fusible metal mercury amalgam; and though

this prevents the glass from being so much strained, it reduces the

adherence of the solder. It is a comfort to be able to solder

aluminium after working for so many years by way of electroplating, or

filing under solder. An alternative method of soldering aluminium

will be described when the electroplating of aluminium is discussed, §

138.

Gilding Glass. In looking over some volumes of the Journal fuer

praktische Chemie, I came across a method of gilding glass due to

Boettger (Journ. f. prakt. Chem. 103, p. 414). After many trials

I believe I am in a position to give definite instructions as to the

best way of carrying out this rather troublesome operation. The films

of gold obtained by the process are very thick, and the appearance of

the gold exceedingly fine. The difficulty lies in the exact

apportionment of the reducing solution. If too much of the reducing

solution be added, the gold deposits in a fine mud, and no coating is

obtained. If, on the other hand, too little of the reducing solution

be added, little or no gold is deposited. The secret of success turns

on exactly hitting the proper proportions.

The reducing solution consists of a mixture of aldehyde and glucose,

and the difficulty I have had in following Boettger's instructions

arose from his specifying "commercial aldehyde" of a certain specific

gravity which it was impossible to reproduce. I did not wish to

specify pure aldehyde, which is not very easily got or stored, and

consequently I have had to determine a criterion as to when the

proportion of reducing solution is properly adjusted.

The aldehyde is best made as required. I employed the ordinary

process as described in Thorpe's Dictionary of Applied Chemistry, by

distilling alcohol, water, sulphuric acid, and manganese dioxide

together. The crude product is mixed with a large quantity of calcium

chloride (dry--not fused), and is rectified once. The process is

stopped when the specific gravity of the product reaches 0.832 at 60°

F. The specific gravity of pure aldehyde is 0.79 nearly.

The following is a modification of Boettger's formula:-

Solution I

1 gram of pure gold is converted into chloride--got acid free--i.e.

to the state represented by AuCl3, and dissolved in 120 cc. of water.

This solution is the equivalent of one containing 6.5 grains of

trichloride to the ounce of water.

Solution II.

6 grams sodium hydrate.

100 grams water.

Solution III.

0.2 grams glucose (bought as pure).

12.6 cubic centimetres 95 per cent alcohol.

12.6 cubic centimetres water.

2.0 cubic centimetres aldehyde, sp. gr. 0.832.

To gild glass these solutions are used in the following proportions by

volume:-

16 parts of No. I.

4 parts of No. II.

0.8 parts of No. III.

The glass is first cleaned well with acid and washed with water: it

is then rinsed with Solution No. III. If it is desired to gild the

inside of a glass vessel, Solution No. III. may be placed in the

vessel first, and the walls of the vessel rinsed round carefully.

Solutions I. and II. are mixed separately and then added

to III.--after about two minutes the whole is well shaken up.

If it be desired to gild a mirror of glass, the glass-plate is

suspended face downwards in a dish of the mixed solutions--care being

taken to rinse the glass with Solution III. first.

If the mixture darkens in from 7' to 10' in diffuse daylight and at

60°F. it will gild well, and it generally pays to make a few trials

in a test tube to arrive at this. If too much reducing solution is

present the liquid will get dark more rapidly, and vice versa. The

gilding will require several hours--as much as twelve hours may be

needed.

The reaction is one of great chemical interest, being one of that

class of reactions which is greatly affected by capillarity. Thus it

occasionally happens that when the reducing solution is not in the

right proportion, gold will be deposited at the surface of the liquid

(so as to form a gilt ring on the inside of a test tube), the

remainder of the gold going down as mud. The gold deposited is at

first transparent to transmitted light and is deeply blue. I thought

this might be due to a trace of copper or silver, but on carefully

purifying the gold no change of colour was noted. If the reducing

solution is present in slightly greater proportions than that given in

the formula, the gold comes down with a richer colour, and has a

tendency to form a mat surface and to separate from the glass. The

gold which is deposited more slowly has a less rich colour but a

brighter surface. The operation should be interrupted when a

sufficient deposit has been obtained, because it is found that the

thicker the deposit, the more lightly is it held to the glass surface.

§ 75. The Use of the Diamond-cutting Wheel.

A matter which is not very well known outside geological circles is

the manipulation of the diamond-cutting wheel, and as this is often of

great use in the physical laboratory, the following notes may not be

out of place. I first became acquainted with the art in connection

with the necessity which arose for me to make galvanometer mirrors out

of fused quartz, and it was then that I discovered with surprise how

difficult it is to obtain information on the point. I desire to

express my indebtedness to my colleagues, Professor David and Mr.

Smeeth, for the instruction they have given me. In what follows I

propose to describe their practice rather than my own, which has been

of a makeshift description. I will therefore select the process of

cutting a slice of rock for microscopical investigation.

§ 76. Arming a Wheel.

Fig. 63.

A convenient wheel is made out of tin-plate, i.e. mild steel sheet,

about one-thirtieth of an inch thick and seven inches in diameter.

This wheel must be quite flat and true, as well as round; too much

pains cannot be taken in securing these qualities. After the wheel is

mounted, it is better to turn it quite true by means of a

watch-maker's "graver" or other suitable tool. The general design of

a rock-cutting machine will be clear from the illustration (Fig. 63).

The wheel being set up correctly, the next step is to arm it with

diamond dust. For this purpose it is before all things necessary that

real diamond dust should be obtained. The best plan is to procure a

bit of "bort" which has been used in a diamond drill, and whose

properties have therefore been tested to some extent. This is ground

in a diamond mortar--or rather hammered in one--and passed through a

sieve having at least 80 threads to the inch. The dust may be

conveniently kept in oil.

To arm the wheel, a little dust and oil is taken on the finger, and

laid on round the periphery of the wheel. A bit of flint or agate is

then held firmly against the edge of the wheel and the latter is

rotated two or three times by hand. The rotation must be quite

slow--say one turn in half a minute--and the flint must be held firmly

and steadily against the wheel. Some operators prefer to hammer the

diamond dust into the wheel with a lump of flint, or agate, but there

is a risk of deforming the wheel in the process. When a new wheel is

set up, it may be necessary to repeat the above process once every

half hour or so till the cutting is satisfactory, but when once a

wheel is well armed it will work for a long time without further

attention.

§ 77. Cutting a Section.

A wheel 7 inches in diameter may be rotated about 500 times per

minute, and will give good results at that speed. The work, as will

be seen from the diagram, is pressed against the edge of the wheel by

a force, which in the case quoted was about the weight of eleven

ounces. This was distributed along a cutting arc of three-quarters of

an inch.

A convenient cutting lubricant is a solution of Castile soap in water,

and this must be freely supplied; if the wheel gets dry it is almost

immediately spoiled owing to the diamond dust being scraped off. In

the figure the lubricant is supplied by a wick running into the

reservoir. I have used both clock oil and ordinary gas-engine oil as

lubricants, with equally satisfactory results. As to the speed of

cutting, in the experiment quoted a bit of rather friable "gabbro,"

measuring three-quarters of an inch on the face by five-eighths of an

inch thick, was cut clean through in six minutes, or by 3000 turns of

the wheel. The travel of the edge was thus between 5000 and 6000

feet, or say 9000 feet, nearly 2 miles, per inch cut.

A good solid rock, like basalt, can be cut into slices of about 3/32

inch thick. A very loose rock is best boiled in Canada balsam, hard

enough to set, before it is put against the wheel.

Instead of a grinding machine a lathe may be employed. The disc is,

of course, mounted on the mandrel, and the work on the slide-rest.

The latter must be disconnected from its feed screws, and a weight

arranged over a pulley so as to keep the work pressed against the

wheel by a constant force.

It may, perhaps, occur to the reader to inquire whether any clearance

in the cut is necessary. The answer is that in all probability, and

in spite of every care, the wheel will wobble enough to give

clearance. If it does not, a little diamond dust rubbed into the side

of the wheel, as well as the edge, will do all that is required. The

edge also, after two or three armings, "burrs" a little, and thus

provides a clearance naturally. It is not unlikely that in the near

future the electric furnace will furnish us with a number of products

capable of replacing the diamond as abrading agents. The cost of the

small amount of diamond dust; required in a laboratory is so small,

however, that it; is doubtful whether any appreciable economy will be,

effected.

§ 78. Grinding Rock Sections, or Thin Slips of any Hard Material.

A note on this is, perhaps, worth making, for the same reasons as were

given for note, § 75, which it naturally follows. Just as

trout-fishing; is described by Mr. Francis as the "art of fine and far

off," [Footnote: In the Badminton Library, volume on Fishing.]

section grinding may be called "the art of Canada balsam cooking," as

follows. A section of rock having been cut from the lump as just

described, it becomes; necessary to grind it down for purposes of

microscopical investigation. For this purpose it is placed on a slip

of glass, and cemented in position by Canada, balsam. Success in the

operation of grinding the mounted section depends almost entirely on

the way in which the mounting is done, and this in its turn depends on

the condition to which the Canada has been brought.

To illustrate the operations, I will describe a specific case, viz.

that of grinding the section of "gabbro"' above described, for

microscopical purposes. One side of the section is probably

sufficiently smooth and plane from the operation of the diamond wheel;

if not, it must be ground by the finger on a slab of iron or gun-metal

with emery and water, the emery passing a sieve of 80 threads to the

inch. The glass base on which the section is to be mounted for

grinding is placed on a bit of iron or copper plate over a Bunsen

burner, and three or four drops of natural Canada balsam are placed

upon it. The section is placed on the plate to heat at the same time.

The temperature must not rise so high as to cause any visible change

in the Canada balsam, except a slight formation of bubbles, which rise

to the surface, and can be blown off. The heating may require to be

continued, say, up to twenty minutes. The progress of the operation

is tested by examining the balsam as to its viscous properties.

An exceedingly simple and accurate way of testing is to dip a pair of

ordinary forceps in the balsam, which may be stirred a little to

secure uniformity. The forceps are introduced with the jaws in

contact, and, as soon as withdrawn, the jaws are allowed to spring

apart, thus drawing out a balsam thread. In a few moments the thread

is cold, and if the forceps be compressed, this thread will bend.

The Canada must be heated until it is just in such a state that on

bringing the jaws together the thread breaks. The forceps may open to

about three-quarters of an inch. If the Canada is more viscous, so

that the thread does not break, the section when cemented by it will

most probably slip on the slide. On the other hand, if the balsam is

more brittle, it will crumble away during the grinding.

Assuming that the proper point has been reached, the section is

mounted with the usual precautions to avoid air bubbles, i.e. by

dropping one edge on the balsam first. When all is cold, the surface

of the section may be ground on an iron plate with emery passing the

80 sieve, till it is about 1/40 inch thick. From this point it must

be reduced on ground glass by flours of emery and water; the rough

particles of the former may be washed out for fine work.

The process of grinding should not take more than half an hour if the

section is properly cut, etc. Beyond this point the allowable

thickness must depend on the nature of the rock; a good general rule

is to get the section just so thin that felspars show the yellow of

the first order in a polarising, microscope. The section is then

finished with, say, two minutes emery or water of Ayr-stone dust. It

is better not to have the surface too smooth.

To transfer the section, the hard Canada round the sides is scraped

away, and the section itself covered with some fresh Canada from the

bottle. It is then warmed till it will slip off when a pin, or the

invaluable dentist's chisel, is pressed against one side. If the

section be very delicate, the cover slip should be placed over it

before it is moved to the proper slide. The Canada used for mounting

is not quite so hard as that employed in grinding, but it should be

hard when cold, i.e. not sticky.

The art of preparing Canada balsam appears to consist in heating it

under such conditions as will ensure its being exposed in thin layers.

I have wasted a good deal of time in trying to bake Canada in

evaporating basins, with the invariable result that it was either over

or under-baked, and got dark in colour during the process.

On reviewing the process of rock section-cutting and mounting as just

described, I cannot help thinking that, if properly systematised, it

could be made much more rapid by the introduction of proper automatic

grinding machinery. It also seems not improbable that a proper

overhaul of available gums and cements would be found to lead to a

cementing material less troublesome than Canada balsam.

§ 79. Cutting Sections of Soft Substances.

Though this art is fully treated of in books on practical biology, it

is occasionally of use to the physicist, and the following note treats

of that part of the subject which is not distinctly biological.

Soft materials, of which thin sections may be required, generally

require to be strengthened before they are cut. For this purpose a

variety of materials are available. The one most generally used is

hard paraffin. The only point requiring attention is the embedding.

The material must be dry.

This is accomplished by soaking in absolute alcohol, i.e. really

absolute alcohol made by shaking up rectified spirit with potassium

carbonate, previously dried, and then digesting for a day with large

excess of quick-lime, making use of an inverted condenser and finally

distilling off the alcohol without allowing it to come in contact with

undried air. After soaking for some time in absolute alcohol, the

material may be transferred to oil of bergamot, or oil of cloves, or

almost any essential oil. After soaking in this long enough to allow

the alcohol to diffuse out, the material may be lifted into a bath of

melted paraffin (melting at, say, 51° C.). The process of soaking is

in some cases made to go more rapidly by exhausting, and, if the

material will stand it, by raising the temperature over 100° C. The

soaking process may require minutes, hours, or days, according to the

size and density of the material; but a few hours are usually

sufficient.

When cold, the sections may be cut in any of the ordinary forms of

microtome.

Another way of embedding is to soak in collodion, and then precipitate

the latter in the material and around it by plunging into nearly

absolute alcohol. The collodion yields a harder matrix than the

paraffin.

Whatever form of cutting machine is employed, the art of sharpening

the knife is the only one requiring any particular notice. The

easiest way of obtaining a knife hard enough to sharpen, is to use a

razor of good quality. If it has to be ground, it is best to do this

on a fine Turkey stone which is conveniently rested on two bits of

rubber tubing, to avoid jarring the blade. Many stones are slightly

cracked, but on no account must the razor be dragged across a crack,

or the edge will suffer.

The necessary and sufficient condition is that the razor must be

worked in little sweeps over the stone, and pressed against the latter

by little more than its own weight, and the grinding must be regular.

The edge may be inspected under a microscope, and it must be perfectly

smooth and even before it will cut sections. A finishing touch may be

given on a leather strap, but it must be done skilfully, otherwise it

is better omitted.

The necessity for providing exceptionally keen and sharp edges arose

in the manufacture of phonographs, where the knife used to turn up the

wax cylinders must leave a perfectly smooth surface. In 1889 this was

being accomplished on an ivory lap fed with a trace of very fine

diamond dust.

I have had this method in mind as a possible solution of the

difficulty of razor-grinding, but have not tried it. I imagine one

would use a soft steel or ivory slip rubbed over with fine diamond

dust and oil by means of an agate. The lap used in the phonograph

works was rotated at a high speed.

§ 80. On the Production of Quartz Threads.

[Footnote: Since this was written an article on the same subject by

Mr. Boys appeared in the Electrician for 1896. The instructions

therein given are in accordance with what I had written, and I have

made no alteration in the text.]

In 1887 the important properties of fused quartz were discovered by

Mr. Vernon Boys (Philosophical Magazine, June 1887, p. 489, "On the

Production, Properties, and Some Suggested Uses of the Finest

Threads"). A detailed study of the properties of quartz threads was

made by Mr. Boys and communicated to the Society of Arts in 1889

(Journal of the Society of Arts, 1889). An independent study of the

subject was made by the present writer in 1889 (Philosophical

Magazine, July 1890, "On the Elastic Constants of Quartz Threads ").

There is also a paper in the Philosophical Magazine for 1894 (vol.

xxxvii. p. 463), by Mr. Boys, on "The Attachment of Quartz Fibres."

This paper also appeared in the Journal of the Physical Society at

about the same date, together with an interesting discussion of the

matter. In the American Journal, Electric Power, for 1894, there is a

series of articles by Professor Nichols on "Galvanometers," in which a

particular method of producing quartz threads is recommended. The

method was originally discovered by Mr. Boys, but he seems to have

made no use of it. A hunt through French and German literature on the

subject has disclosed nothing of interest--nothing indeed which

cannot be found in the papers mentioned.

§ 81. Quartz fibres have two great advantages over other forms of

suspension when employed for any kind of torsion balance, from an

ordinary more or less "astatic" galvanometer to the Cavendish

apparatus. In the first place the actual strength of the fibres under

longitudinal stress is remarkably high, ranging from fifty to seventy

tons weight per square inch of section, and even more than this in the

case of very fine threads; the second and more important point in

favour of quartz depends on the wide limits within which cylindrical

threads of this material obey the simplest possible law of torsion,

i.e. the law that for a given thread carrying a given weight at a

given temperature and having one end clamped, the twist about the axis

of figure produced by a turning moment applied at the free end is

proportional simply to the moment of the twisting forces, and is

independent of the previous history of the thread.

It is to be noted, however, that the torsional resilience of quartz as

tested by the above law is not so perfect but that our instrumental

means allow us to detect its imperfections, and thus to satisfy

ourselves that threads made of quartz are not things standing apart

from all other materials, except in the sense that the limits within

which they may be twisted without deviating in their behaviour from

the law of strict proportionality by more than some unassigned small

quantity, are phenomenally wide.

A torsion balance--if we except the case of certain spiral

springs--is almost always called upon for information as to the magnitude

of very small forces, and for this purpose it is not essential merely

that some law of twisting should be exactly obeyed, but also that the

resistance to twisting of the suspension should be small.

Now, regarded merely as a substance possessing elastic rigidity,

quartz is markedly inferior to the majority of materials, for it is

very stiff indeed; its utility depends as much as anything upon its

great strength, for this allows us to, use threads of exceeding

fineness. In addition to this it must be possible, and moreover

readily possible, to obtain threads of uniform section over a

sufficient length, or the rate of twist per unit length of the thread

will vary in practice from point to point, so that the limits of

allowable twist averaged over the whole thread may not be exceeded,

and yet they may be greatly overpassed at particular points of the

thread.

It is interesting to note that in the case of quartz we not only have

a means for readily producing very uniform cylindrical threads, but

that the limits of allowable rate of twist are so wide that a small

departure from uniformity of section produces much less inconvenience

than in the case of any other known substance.

§ 82. There are three methods generally in use for drawing quartz

fibres, all depending on the fact that quartz when fused is so viscous

that it may be drawn into threads of great length, without these

threads breaking up into drops, or indeed without their showing any

sign of doing so. The surface tension of the melted quartz must,

however, be very considerable, as may be seen by examining the shape

of a drop of the molten material, and this suffices to impress a

rigidly cylindrical form upon the thread, the great viscosity

apparently damping down all oscillation.

The first method is the one originally employed by Mr. Boys. A needle

of quartz is melted somewhere in its length and is then drawn out

rapidly by a light arrow, to which one end of the needle is attached,

and which is projected from a kind of crossbow.

A modification of this method, which the writer has found of service

when very thick threads are required, is to replace the bow and arrow

by a kind of catapult.

The third method, which yields threads of almost unmanageable

fineness, depends on the experimental fact that when a fine point of

quartz is held in a high pressure oxygen gas blow-pipe flame, the

friction of the flame gases suffices to overcome the tendency of the

capillary forces to produce a spherical drop, and actually causes a

fine thread to be projected outwards in the direction of the flame.

§ 83. A preliminary operation to any method is the production of a

stick of fused quartz. This is managed as follows. A rock crystal or

quartz pebble is selected and examined. It must be perfectly white,

transparent, and free from dirt. Surface impurity can of course be

got rid of by means of a grindstone. The crystal is placed in a

perfectly clean Stourbridge clay crucible, furnished with a cover, and

heated to bright redness for about an hour in a clean fire or in a

Fletcher's gas furnace. The contents of the crucible are turned out

when sufficiently cool on to a clean brick or bit of slate. It will

be found that the crystal is completely broken up and the fragments

must be examined in case any of them have become contaminated by the

crucible, but this will not have happened if the temperature did not

rise beyond a bright red heat.

The heap of fragments being found satisfactory, the next thing is to

fuse some of the pieces together. Unless the preliminary heating has

been efficiently carried out this will prove an annoying task, because

a rock crystal generally contains so much water that it splinters

under the blow-pipe in a very persistent manner. There are two ways

of assembling the fragments. One is to place two tiles or bricks on

edge about the heap of quartz lying upon a third tile, so that the

heap occupies the angular corner or nook formed by the tiles (Fig.

64).

The oxygas blow-pipe previously described is adjusted to give its

hottest flame, the bags being weighted by at least two hundredweight,

if of the size described (see § 15).

The tip of the inner cone of the blow-pipe is brought to bear directly

upon one of the fragments, and if the operation is performed boldly it

will be found that the surface of the fragment can be fused, and the

fragment thus caused to hold together before the lower side gets hot

enough to suffer any contamination from the tile or brick. A second

fragment may be treated in the same way, and then a third, and so on.

Finally, the fragments may be fused together slightly at the corners,

and a stick may thus be formed. Of course a good deal of cracking and

splitting of the fragments takes place in the process; the best

pieces to operate upon are those which are well cracked to begin with,

and that in such a way that the little fragments are interlocked.

An alternative method which has some advantages is to arm a pair of

forceps with two stout platinum jaws, say an inch and a half long, and

flattened a little at the ends. The fragments are held in these

platinum forceps and the blow-pipe applied as before. This method

works very well in adding to a rod which has already been partly

formed, but the jaws require constant renewals. The first fragment

which is fused sufficiently to cohere may also be fused to a bit of

tobacco pipe, or hard glass tube or rod, and the quartz stick

gradually built up by fusing fresh pieces on to the one already in

position.

Fig. 64.

Since the glass or pipeclay will contaminate the quartz which has been

fused on to it, it is necessary to discard the end pieces at the close

of the operation. A string of fragments having been collected and

stuck together, the next step is to fuse them down into a uniform rod.

This is easily done by holding the string in the blow-pipe flame and

allowing it to fuse down. Twisting the fused part has a good effect

in assisting the operation. It is desirable to use a large jet and as

powerful a flame as can be obtained during this part of the operation.

The final result should be a rod, say two or three inches long and

one-eighth of an inch thick, which will in most cases contain a large

number of air bubbles. Since the presence of drawn-out bubbles cannot

be advantageous, it is often desirable to get rid of them, and this

can conveniently be done at the present stage. The process at best

is rather tedious; it consists in drawing the quartz down very fine

before an intense flame, in order to allow the bubbles to get close

enough to the surface to burst. A considerable loss of material

invariably occurs during the process; for whenever the thin rod

separates into two bits the process of flame-drawing of threads goes

on, and entails a certain waste; moreover, the quartz in fine

filaments is probably partially volatilised.

Sooner or later, however, a sufficient length of bubble-free quartz

can be obtained. It must not be supposed that it is always necessary

to eliminate bubbles as perfectly as is contemplated in the foregoing

description of the treatment, but for special purposes it may be

essential to do so, and in any case the reader's attention is directed

to a possible source of error.

It may be mentioned in connection with this matter that crystals of

quartz may look perfectly white and clear, and yet contain impurity.

For instance, traces of sodium are generally present, and lithium was

found in large spectroscopic quantity in five out of six samples of

the purest crystals in my laboratory. The presence of lithium in rock

crystal has also been detected by Tegetmeier (Vied. Ann, xli. p.

19, 1890).

After some practice in preparing rods and freeing them of bubbles the

operator will notice a distinct difference in the fusibility of the

samples of quartz he investigates, though all may appear equally pure

to the unaided eye. It should be mentioned, however, that high

infusibility cannot always be taken as a test of purity, for the most

infusible, or rather most viscous, sample examined by the writer

contained more lithium than some less viscous samples.

Fig. 65.

During the process of freeing the quartz from bubbles the lithium and

sodium will be found to burn away, or at all events to disappear.

A rod of quartz, say three inches long, one-sixteenth of an inch in

diameter, and free from bubbles for half an inch of its length, even

when examined by a strong lens, is suitable for drawing into threads.

The rod is manipulated exactly in the manner described under

glass-blowing, and is finally drawn down at the bubble free part into

a needle, say 0.02 inch in diameter (No. 25 on the Birmingham wire

gauge), and 2 inches long.

Fig. 66.

There is one peculiarity about fused quartz which renders its

manipulation easier than that of glass--it is impossible to break

fused quartz, however suddenly it be thrust into the blow-pipe flame.

A rod having a diameter of three-sixteenths of an inch--and perhaps

much more--may be brought right up to the tip of the inner cone of

the oxy-gas flame and held there-till one side fuses, the other being

comparatively cool, without the slightest fear of precipitating a

smash. In seven years' experience I have never seen a bit of once

fused quartz broken by sudden heating; whether it might be done if

sufficient precautions were taken I do not know.

The reason of the fortunate peculiarity of quartz in this respect is,

I presume, to be found in the fact that quartz once it has been fused

is really a very strong material indeed, and is also probably the

least expansible substance known. From some experiments of the writer

upon the subject, it may be concluded that at the most quartz which

has been fused expands only about one-fifth as fast as flint-glass, at

all events between 20° and 70° C.

§ 84. Drawing Quartz Threads.

The thick end of the rod of quartz is held in the fingers or

occasionally in a clip. The end of the fine point is attached to a

straw arrow by means of a little sealing-wax. The arrow is laid on

the stock of a crossbow in the proper position for firing. See

Figs. 67 and 68, which practically explain themselves.

The needle is heated by the blow-pipe till a minute length is in a

state of uniform fusion; the arrow is then let fly, when it draws a

thread out with it. The arrow is preferably allowed to strike a

wooden target placed, say, 30 feet away from the bow, and a width of

black glazed calico is laid under the line of fire to catch the thread

or arrow if it falls short. The general arrangements will be obvious

from the figure.

The bow is of pine in the case where very long thin threads are

required, though for ordinary purposes I have found a bow of

lance-wood succeed quite as well. The trigger of the bow consists of

a simple pin passing through the stock and fastened at its lower end

to a string connected with a board which can be depressed by foot. In

the figure an ordinary trigger is shown, but the pin does just as

well.

Fig 67.

The arrow is made out of about 6 inches of straw, plugged up aft by a

small plug of pine or willow fastened in with sealing-wax, and

projecting backwards one-eighth of an inch. This projection serves a

double purpose: it gives a point of attachment for the quartz needle,

and on firing the bow it forms a resisting anvil on which the string

of the bow impinges. The head of the arrow is formed by a large

needle stuck in with sealing-wax, and heavy enough to bring the centre

of gravity of the arrow forward of one-third of its length, the

condition of stability in flight.

Fig. 68.

It is not necessary to employ any feathering for these arrows; though

I have occasionally used feathers or mica to "wing the shaft" no

advantage has resulted therefrom.

To get fine threads a high velocity is essential. This is obtained by

considering (and acting upon) the principles involved. The bow may be

regarded as a doubly-tapering rod clamped at the middle. After

deflection it returns towards its equilibrium position at a rate

depending in general terms on the elastic forces brought into play,

directly, and on the effective moment of inertia of the rod, inversely

(see Rayleigh, Sound, vol. ii. chap. viii.) If the mass of the

arrow is negligible compared with the bow, the rate at which the arrow

moves is practically determined by that attained by the end of the

bow, which is a maximum in crossing its equilibrium position.

The extent to which the arrow profits by this velocity depends on the

way the bow is strung. It will be greatest when the string is

perpendicular to the bow when passing its equilibrium position; or in

other words, when the string is infinitely long. Since the string has

mass, however, it is not permissible to make it too long, or its

weight begins to make itself felt, and a point is soon reached at

which the geometrical gain in string velocity is compensated for by

the total loss of velocity due to the inertia of the string. In

practice it is sufficient to use a string 10 per cent longer than the

bow.

It is well to use a light fiddle string, served with waxed silk at the

trigger catch; if this be omitted the gut gets worn through very

quickly. In order to decide how far it is permissible to bend the

bow, the quickest way is to make a rough experiment on a bit of the

same plank from which the bow is to be cut, and then to allow a small

factor of safety. In the figure the bow is of lance-wood and is more

bent than would be suitable for pine.

The bow itself is tapered from the middle outwards just like any other

bow. If thick threads are required, the above considerations are

modified by the fact that quartz opposes a considerable resistance to

drawing, and that consequently the arrow must not only have a high

velocity, but a fair supply of energy as well; in other words, it

must be heavy. A thin pine arrow instead of a straw generally does

very well, but in this case the advantage of using pine for the bow

vanishes; and in fact lance-wood does better, owing to the greater

displacement which it will stand without breaking. This of course

only means that a greater store of energy can be accumulated at one

bending.

I had occasion to investigate whether the unavoidable spin of an arrow

about its axis produces any effect on the thread, and for this purpose

made arrows with inertia bars thrust through the head, i.e. an arrow

with a bit of wire run through it, perpendicular to its

length--forming a cross in fact--the arms of the cross being weighted

at the extreme ends by shot. This form of arrow has a considerable

moment of inertia about its longer axis, and consequently rotates less

than a mere straw, provided that the couples tending to produce rotation

are not increased by the cross arm, or the velocity too much reduced.

Shooting one of these arrows slowly, I could see that it did not

rotate, and when fired at a high velocity, it generally arrived at the

target (placed at varying distances front bow) with the arms nearly

horizontal, thus showing that it probably did not rotate much.

I did not succeed in this at the first trial, by any means. The

threads got in this way were no better than those made with a single

straw, whence we may conclude very provisionally that the spin of the

arrow has only a small effect, if any, on the quality of the threads.

Feathering the arrow, in my experience, tends, if anything to make it

spin more; for one thing, because it is practically impossible to lay

the feathering on straight.

After the arrow is shot, it remains to gather in the thread, and if

the latter is at all thin, we have a rather troublesome job. In a

thread thirty or forty feet long, the most uniform part generally lies

in the middle if the thread is thin, i.e. of the order of a

ten-thousandth of an inch in diameter. If the thread is thick the

most uniform part may be anywhere. The part of the thread required is

generally best isolated by passing a slip of paper under it at each

end and cementing the thread to the paper by means of a little

paraffin or soft wax, and then cutting off the outer portions. One

bit of paper may then be lifted off the calico, and the thread will

carry the other bit. In this way the thread may be taken to a

blackened board, where it may be mounted for stock.

By passing the two ends of the thread under a microscope, or rather by

breaking bits off the two ends and examining them together, it is easy

to form an Opinion as to uniformity.

Mr. Boys has employed an optical method of examining threads, but the

writer has invariably found a high-power microscope more convenient

and capable of giving more exact information as to the diameter of the

threads.

The beginner--or indeed the practised hand--need not expect to get a

thread of the exact dimensions required at the first shot. A little

experience is necessary to enable one to judge of the right thickness

of the needle for a thread of given diameter. The threads are so

easily shot, however, that a few trials take up very little time and

generally afford quite sufficient experience to enable a thread of any

required diameter to be prepared.

It is no use attempting to heat an appreciable length of needle; if

this be done the thread almost invariably has a thick part about the

middle of its length.. It is sufficient to fuse at most about

one-twentieth of an inch along the needle before firing off the bow.

This can be done by means of the smaller oxygas blow-pipe jet

described in the article on blow-pipes for glass-blowing, § 14. The

flame must of course be turned down so as to be of a suitable size. A

sufficiently small flame may be got from almost any jet.

If the needle be not equally heated all round, the thread tends to be

curly; indeed by means of the catapult, threads may be pulled which,

when broken, tend to coil up like the balance-springs of watches, if

only care be taken to have one side of the needle much hotter than the

other.

§ 85. When examining bits of threads, say thicker than the

two-thousandth of an inch, under the microscope it is convenient to

use a film of glycerine stained with some kind of dye, in order to

render the thread more sharply visible. The thread is mounted beneath

a cover slip, and a drop of the stained glycerine allowed to run in.

Such a treatment gives the image of the thread a sharply defined edge

3 and the contrast between the whiteness of the thread and the colour

of the background allows measurements to be made with great ease.

On the whole the easiest way of measuring the diameter of a thick

thread is to use a measuring microscope, i.e. one in which the lens

system can be displaced along a plane bed by means of a finely cut

micrometer screw. The instruments made by the Cambridge Scientific

Instrument Company do fairly well. Direct measurements up to 0.0001

inch are easily made by means of a microscope provided with a Zeiss

"A" objective, and rather smaller differences of thickness can be made

out by it. For thin threads the method next to be described is more

fitting, because higher powers can be more conveniently used.

In this method an ordinary microscope is employed together with a

scale micrometer, and either an eyepiece micrometer, or a camera and

subsidiary scale. The eyepiece micrometer is the more convenient. If

a camera be employed, i.e. such an one as is supplied by Zeiss, it is

astonishing how the accuracy of observation may be increased by

attending carefully to the illumination of both the subsidiary scale

and of the thread. The two images should be as far as possible of

equal brightness, and for this purpose it will be found requisite to

employ small screens.

The detail of making a measurement by means of the micrometer eyepiece

is very simple. The thread is arranged on the stage so as to point

towards the observer, and the apparent diameter is read off on the

eyepiece scale. In order to calibrate the latter it is only necessary

to replace the thread by the stage micrometer, and to observe the

number of stage micrometer divisions occupying the space in the

eyepiece micrometer formerly occupied by the thread. It is essential

that both thread and stage micrometer should occupy the same position

in the field, for errors due to unequal distortion may otherwise

become of importance. For this reason it is best to utilise the

centre of the field only.

The same remark applies to measurements by means of the camera, where

the image of the thread is projected against the reflected image of

the subsidiary scale laid alongside the microscope. In this case the

value of the subsidiary scale divisions must be obtained from the

divisions of the stage micrometer, coinciding as nearly as possible

with the position occupied by the thread. Before commencing a

measurement the screens are moved about till both images appear

equally bright.

Threads up to about one twenty-thousandth of an inch in diameter may

be sufficiently well measured by means of a Zeiss "4 centimetre

apochromatic object-glass" and an eyepiece "No. 6" with sixteen

centimetre tube length. [Footnote: The objective certainly had "4 cm."

marked on it, but the focal length appeared to be about I.5 mm. only.]

§ 86. Drawing Threads by the Catapult.

The bow-and-arrow method fails when threads of a greater diameter than

about 0.0015 inch are required--at least if any reasonable uniformity

be demanded, and no radical change in the bow and arrow be carried

out.

Thus in the writer's laboratory a thread of about this diameter,

within 1/10000 of an inch-13 inches long and free from air

bubbles--was required. A fortnight's work by a most skilful operator

only resulted in the production of two lengths satisfying the

conditions.

The greatest loss of time occurs in the examination of the thread by

means of the microscope.

Threads for galvanometer suspensions are conveniently from 0.0001 to

0.0004 inch in diameter, and are much more easily made and got uniform

than thicker threads, to the production of which the catapult method

applies.

A reference to the diagram will make the construction of the

instrument quite clear. The moving end of the quartz is attached to a

small boxwood slider working on a tubular girder or between wires.

The quartz is secured in position by clamps shown at A and B, and

motion is imparted to the slider by a stretched piece of catapult

elastic (C). An easy means of regulating the pull of the elastic is

to hold it back by a loop of string whose length can be varied by

twisting it round a pin.

Fig. 69. [Footnote: For greater clearness of drawing, the tube

carrying the slider is shown somewhat higher above the base than is

convenient in practice; and the slide itself is shown too thin in the

direction of the hole through it.]

Since it is not permissible to allow the slider to rebound at the end

of its journey, some such arrangement of breaks as is shown must be

adopted. In the diagram the bottom of the slider runs on to a brass

spring between the girder and the base of the appliance, and so gets

jammed; the spiral spring acts merely as an additional guard. The

diagram does not show the lower spring very clearly; it is a mere

strip lying in the groove.

A rod of quartz, with a needle at one end, is prepared as before and

secured in the clamps. During the operation of fastening down the

clamps, there is some danger of breaking the needle, and consequently

it is advisable to soften the latter before and while adjusting the

second clamp.

The process of drawing a thread by this method is exactly similar to

the operation already described in connection with the arrow method.

Though short thick threads form the product generally obtained from

the catapult, it must not be supposed that thin threads cannot be

obtained in this way. If a short length of a very fine needle be

heated, it will be found to yield threads quite fine enough for

ordinary suspension purposes, but naturally not so uniform as those

obtained from the 40-foot lengths obtainable by the bow-and-arrow

method.

It is easy to make spiral quartz springs resembling watch

balance-springs by means of the catapult. All that is necessary is to

see that the quartz is rather unequally heated before the shot is

fired. In the future it is by no means impossible that such springs

may have a real value, for the rigidity of quartz is known to increase

as temperature rises. Hence it is probable that the springs would

become stiffer as temperature rises, even though they work chiefly by

bending, and little or not at all by twisting. As this is the kind of

temperature variation required to compensate an uncompensated watch

balance wheel, it may turn out to have some value.

§ 87. Drawing Threads by the Flame alone.

A stick of quartz is drawn down to a fine point, and the tip of this

point is held in the blow-pipe flame in the position shown in Fig.

70.

Fig. 70.

The friction of the flame gases is found to be sufficient to carry

forward the fused quartz and to draw it into threads in spite of the

influence of the capillary forces. If a sheet of paper be suspended

at a distance of two or three feet in front of the blow-pipe flame, it

will be found to be covered with fine threads tangled together into a

cobwebby mass. As this method is an exceedingly simple one of

obtaining threads, I have endeavoured to reduce it to a systematic

operation.

A sheet of cardboard, about two feet square, is painted dead black and

suspended horizontally, painted side downwards (Fig. 70, A), at a

height of about two feet above the blow-pipe flame. The latter is

adjusted so as to point almost vertically upwards and towards the

centre of the cardboard. A few half-inch pins are thrust through the

card from the upper surface and pushed home; about one dozen pins

scattered over the surface will be sufficient. Their object is to

prevent the threads being carried away round the edge of the screen.

The flame from the jet described so often is fed from gas bags

weighted to about eighty pounds per square foot of (one) surface,

i.e. "4-foot" bags require from three to four hundredweight to give

an advantageous pressure. [Footnote: The resulting threads were really

too fine for convenient manipulation, so that unless extremely fine

threads are required it will be better to reduce the pressure of the

gases considerably.]

Two sticks of quartz are introduced and caused to meet just in front

of the inner cone--the hottest part of the flame. They are then

drawn apart so as to form a fine neck, which softens and is bent in

the direction of motion of the flame gases. When fusion is complete

the neck separates into two parts, and a thread is drawn from each of

them. By alternately lightly touching the rods together, and drawing

them apart, quite a mass of threads may be obtained in two or three

minutes, when the process should be stopped. If too many threads get

entangled in the pins, one gives one's self the unnecessary trouble of

separating them. On taking down the card it will be found that the

threads have been caught by the pins; but the card now being laid

black side upwards, the former easily slip off the points.

Threads at least a foot long, and perhaps vastly longer, may be

obtained by this method, and are extraordinarily fine. When I first

read Professor Nichols' statement (Electric Power, 1894) as to the

value of these fibres for galvanometer purposes, I was rather

sceptical on the ground that the threads would tend to get annealed by

being drawn gradually, instead of suddenly, from a place of intense

heat to regions of lower temperature.

Now annealing threads by a Bunsen makes them rotten. The threads

being immersed in the hot flame gases could only cool at the same rate

as the gas, and it was not--and is not--clear to me that annealing

of the threads can be avoided. On the other hand, it may be possible

that a thread cooled slowly from the first does not suffer in the same

way as a cold thread would do when annealed in a Bunsen flame.

Again the velocity of the gases is beyond doubt exceedingly high, so

that the annealing, even supposing it to be deleterious, might not be

carried very far. Threads drawn by this method and measured "dry,"

i.e. by mounting them on a slide without the addition of any liquid,

turned out to have a diameter of about 1/20000 of an inch.

I do not think I could manage to mount such fine threads without very

special trouble. All the threads lying on the board, however, were

found in reality to consist of three or four separate threads, and

there is no reason why several threads should not be mounted in

parallel, provided, of course, that they are equally stretched and

touching each other. Equality of tension in the mounting could be

secured by making one attachment good, then cementing the other

attachment to the other end of the threads, and "drawing" the two

attachments slightly apart at the moment the cement commences to set.

This method may turn out to be very valuable, for, so far as I can

see, the carrying power would be increased without an increase of

torsional stiffness of anything like so high an order as would be the

case were one thread only employed. On the other hand, the law of

torsion could hardly be quite so simple, at all events, to the second

order of approximations.

§ 88. Properties of Threads.

A large number of experiments on the numerical values of the elastic

constants of quartz threads have been made by Mr. Boys and his

students, and by the writer. As the methods employed were quite

distinct and the results wholly independent, and yet in good agreement

with each other, a rounded average may be accepted with considerable

confidence.

TENACITY OF QUARTZ FIBRES (BOYS).

Diameter of Thread.

Tenacity in Tons' Weight per Square Inch of Section.

Tenacity in Dynes per Square Centimetre.

Inches

Centimetres

0.00069

0.00175

51.7

8 X 109

0.00019

0.00048

74.5

11.5 X 109

Rounded mean of Boys' and Threlfall's results:

Young's Modulus at 20° C,

5.6 X 1011 C.G.S.

Modulus of Simple Rigidity at 20° C,

2.65 X 1011 C.G.S.

Modulus of Incompressibility,

1.4 X 1011 C.G.S.

Modulus of Torsion,

3.7 X 1011 C.G.S.

Approximate coefficient of linear expansion of quartz per degree

between 80° C. and 30° C. is 0.0000017 (Threlfall = loc. cit.).

This must be regarded with some suspicion, as the data were not

concordant. There is no doubt, however, about the extreme

inexpansibility of quartz.

Temperature coefficient of modulus of torsional rigidity per degree

centigrade, 22° to 98° C, 0.000133

Ditto, absolute simple rigidity, 0.000128 (Threlfall).

Limit of allowable rate of twist in round numbers is, one-third turn

per centimetre, in a fibre 0.01 cm. diameter.

The limiting rate is probably roughly inversely as the diameter.

Attention must be called to the rapid increase in the torsional

rigidity of these threads as the temperature rises. A quartz spiral

spring-balance will be appreciably stronger in hot weather.

§ 89. In the majority of instances in which quartz threads are

applied in the laboratory, it is desirable to keep the coefficient of

torsion as small as possible, and hence threads are used as fine as

possible.

It is convenient to remember that a thread 0.0014 cm. or 0.0007 inch

in diameter breaks with a weight of about ten grammes, and may

conveniently be employed to carry, say, five grammes. With threads

three times finer the breaking strength per unit area increases, say,

50 per cent. In ordinary practice--galvanometric work for

instance--where it is desirable to use a thread as fine and short as

possible to sustain a weight up to, say, half a gramme, it will be

found that fibres five centimetres long or over give no trouble

through defect of elastic properties. A factor of safety of two is

a fair allowance when loading threads.

No difficulty will be experienced in mounting threads having a

diameter of 0.0002 inch or over. With finer threads it is necessary

to employ very dark backgrounds (Mr. Boys uses the darkness of a

slightly opened drawer), or the threads cannot be sufficiently well

seen.

In the case of instruments in which threads remain highly twisted for

long periods of time, the above rule as to the safe limit of twist

does not allow of a sufficient margin; it is only applicable to

galvanometric and similar purposes.

The cause of the increase in tenacity as the diameter diminishes is at

present unknown. It is due neither to an effect of annealing

(annealed threads are rotten), nor is it a skin effect, nor is it due

to the cooling of the thread under higher capillary pressure. It is,

however, possible that it may be associated with some kind of

permanent set taken by the fibres during the stage of passage from the

liquid to the solid state.

§ 90. On the Attachment of Quartz Fibres.

For many purposes it is sufficient to cement the fibres in position by

means of ordinary yellow shellac, but where very great accuracy is

aimed at, the shellac (being itself imperfectly elastic and exposed to

shearing stress) imposes its imperfections on the whole system. This

source of error can be got over by soldering the threads in position.

Attempts were made by the writer in this direction, with fair success,

in 1889, but as Mr. Boys has carried the art to a high degree of

perfection, I will suppress the description of my own method and

describe his in preference. It has, of course, been frequently

repeated in my laboratory.

In many cases, however, if not in all, it may be replaced by Margot

soldering, as already described, a note on the application of which to

this purpose will follow.

A thread of the proper diameter having been selected, it is cut to the

right length. With fine threads this is not always a perfectly easy

matter. The best way is for the operator to station himself facing a

good light, not sunlight, which is too tiring to the eye, but bright

diffused light. The thread will be furnished with bits of paper stuck

on with paraffin at both ends, as already described.

A rough sketch of the apparatus--or, at all events, two lines showing

the exact length which the free part of the thread must have--are

marked on a smooth board, and this is supported with its plane

vertical. The thread is held against the board, and the upper piece

of paper is stuck lightly to the board with a trace of soft wax, so

that the lower edge of the paper is at any desired height above the

upper mark. This distance is measured, and forms the length of thread

allowed to overlap the support. A second bit of paper is attached

below the lower mark, a margin for the attachment of the lower end

being measured and left as before. The thread will be most easily

seen if the board is painted a dead black.

If it is desired to attach the thread to its supports merely by

shellac, this is practically all that needs to be done. The supports

should resemble large pins. The upper support will be a brass wire in

most cases, and will require to be filed away as shown in the sketch

(Fig. 71). It is then coated with shellac by heating and rubbing

upon the shellac. As previously noted, the shellac must not be

overheated.

The thread is cut off below the lower slip of paper, and the upper

support being conveniently laid in a horizontal position on another

dead-black surface, the thread is carried to it and laid as designed

against the shellac, which is now cold. When the thread is in place,

a soldering iron is put against the brass wire, and the shellac

gradually melted till it closes over the thread.

Fig. 71.

The iron is then withdrawn and the thread pulled away from the point

for one-twentieth of an inch or less. This ensures that the thread

makes proper contact with the cement, and also that it is free from

kinks; of course, it must leave the cement in the proper direction. A

similar process is next carried out with respect to the lower

attachment, and the ends of the thread are neatly trimmed off.

Both ends of the thread being secured, the next step is to transfer

the upper support to a clip stand, the suspended parts being held by

hand, so that the weight comes on the thread very gradually. In this

way it will be easily seen whether the thread is bent where it enters

the shellac, and should this be the case, a hot iron must be brought

up to the shellac and the error rectified.

When both the support and the suspended parts are brought nearly to

the required bearing, the hot iron is held for a moment close up to

each attachment, the hand being held close below but not touching the

suspended parts, and both attachments are allowed to straighten

themselves out naturally.

These details may appear tiresome, and so they are when written out at

length, but the time occupied in carrying them out is very short, and

quartz threads break easily, unless the pull upon them is accurately

in the direction of their length at all points.

In the event of its being decided to attach the thread by soldering,

the process is rather more expensive in time, but not otherwise more

troublesome.

Fig. 72. Fig. 73.

The thread being cut as before to the proper length, little bits of

aluminium foil are smeared all over with melted shellac and suspended

from the thread replacing the paper slips before described. It is

important that no paraffin should be allowed to touch the thread

anywhere near a point intended to be soldered. The thread is hung up

from a clip stand by one of the bits of foil, and the lower end is

washed by dipping it into strong nitric acid for a moment and thence

into water. The object of smearing the foils all over with shellac is

to prevent them being acted upon by the acid. The threads are not

very easily washed acid free, but the process may be assisted by means

of a fine camel's-hair pencil.

Some silvering solution made as described (§ 65) is put into a test

tube; the thread, after rinsing with distilled water, is lowered into

the solution so far as is required, and is allowed to receive a

coating of silver. It has been observed that the coating of silver

must not be too thick--not sufficiently thick to be opaque. A watch

may be kept on the process by immersing a minute strip of mica

alongside the thread.

The silvered thread is rinsed with distilled water and allowed to dry.

Meanwhile the other end of the thread may be silvered. When both ends

are silvered the process of coppering by electro deposit is commenced.

A test tube is partially filled with a ten per cent solution of

sulphate of copper, and several copper wires are dipped into it to

form an anode. The thread is lowered carefully into the solution so

as not to introduce air bubbles, and the silvered part is allowed to

project far enough above the surface of the solution to come in

contact with a fine copper wire. The circuit is closed through a

Leclanché cell and a resistance box.

It is as well to begin with a fair resistance, say 100 ohms out in the

box, and the progress of the deposit is watched by means of a

low-power microscope set up in front of the thread. If the copper

appears to come down in a granular form, the resistance is too small

and must be increased; if no headway appears to be made, the

resistance must be diminished.

As soon as a fair coat of copper has come down, i.e. when the

diameter of the thread is about doubled, the process is interrupted.

The thread is withdrawn, washed, dipped in a solution of chloride of

zinc, and carefully tinned by dragging it over a small clean drop of

solder on a soldering bit.

During this part of the process the shellac is apt to get melted if

the iron is held too close, so that it is advisable to begin by making

the thread somewhat over long. The end of the thread must only be

trimmed off at the conclusion of the operation, i.e. after the thread

is soldered up. The thread is attached to the previously tinned

supports much in the same way as has been described under the head of

shellac attachments. It does not very much matter whether both ends

are coppered before one is soldered up or not. At the conclusion of

the whole process the superfluous copper and silver are dissolved off

by a little hot strong nitric acid applied on a glass hair pencil.

This is best done by holding the thread horizontally with the

assistance of clip stands.

If the thread is too delicate to bear brushing, the nitric acid may be

applied by pouring out a big drop into a bit of platinum foil and

holding this below the thread so as to touch it lightly. The

dissolving of the copper and silver is, of course, followed by copious

washing with hot water. This process is more laborious than might be

imagined, but it may be shortened by heating the platinum foil

supporting the water (Fig. 74).

Fig. 74

The washing part of the process is, in the opinion of the writer, the

most difficult part of the whole business, and it requires to be very

thorough, or the thread will end by drawing out of the solder. In

many cases it is better to try to do without any application of nitric

acid at all, but, of course, this involves silvering and coppering to

exact distances from the ends of the thread--at all events, in

apparatus where the effective length of the thread is narrowly

prescribed.

It is important not to leave the active parts of the thread

appreciably silvered, for the sake of avoiding zero changes due to the

imperfect elasticity of the silver. In this soldering process

ordinary tinman's solder may be employed; it must be applied very

free from dust or oxide.

§ 91. Other Modes of soldering Quartz.

Thick rods of quartz may be treated for attachment by solder in the

same way as glass was treated by Professor Kundt to get a foundation

for his electrolytically deposited prisms. [Footnote: See Appendix at

end of book.]

The application of a drop of a strong solution of platinum

tetrachloride to the rod will, on drying, give rise to a film of the

dry salt, and this may be reduced in the luminous gas flame. During

the process, however, the quartz is apt to get rotten, especially if

the temperature has been anything approaching a full red heat. The

resulting platinum deposit adheres very strongly to the quartz, and

may be soldered to as before. This method has been employed by the

writer with success since 1887, and may even be extended to thick

threads.

It was also found that fusible metal either stuck to or contracted

upon clean quartz so as to make a firm joint. In the light of M.

Margot's researches (already described), it occurred to me that

perhaps my experience was only a special case of the phenomena of

adhesion investigated with so much success by M. Margot. I therefore

tried whether the alloy of tin and zinc used for soldering aluminium

would stick to quartz, and instantly found that this was indeed the

case.

Adhesion between the alloy and perfectly clean quartz takes place

almost without rubbing. A rod of quartz thus "tinned" can be soldered

up to anything to which solder will stick, at once. On applying the

method to thick quartz threads, success was instantaneous (the threads

were some preserved for ordinary galvanometer suspensions); but when

the method was applied to very fine threads, great difficulty in

tinning the threads was experienced. The operation is best performed

by having the alloy on the end of an aluminium soldering bit, and

taking care that it is perfectly free from oxide before the thread is

drawn across it. There was no difficulty in soldering a thread

"tinned" in this manner to a copper wire with tinman's solder, and

the joint appeared perfect, the thread breaking finally at about an

inch away from the joint.

I allow Mr. Boys' method to stand as I have written it, simply because

I have not had time as yet to make thorough tests of the durability of

"Margot" joints on the finest threads; but I have practically no

doubt as to its perfect applicability, provided always that the solder

can be got clean enough when melted on the bit. Very fine threads

will require to be stretched before tinning, in order to enable them

to break through the capillary barrier of the surface of the melted

solder.

§ 92. Soldering.

It is almost unfair to the arts of the glass-blower or optician to

describe them side by side with the humble trade of soldering.

Nevertheless, no accomplishment of a mechanical kind is so serviceable

to the physicist as handiness with the soldering bit; and, as a rule,

there is no other exercise in which the average student shows such

lamentable incapacity. The following remarks on the subject are

therefore addressed to persons presumably quite ignorant of the way in

which soldering is carried out, and do not profess to be more than of

the most elementary character.

For laboratory purposes three kinds of solder are in general

sufficient. One is the ordinary tinman's solder composed of lead and

tin. The second is "spelter," or soft fusible brass, and the third is

an alloy of silver and brass called silver solder.

Tinman's solder is used for most purposes where high temperatures are

not required, or where the apparatus is intended to be temporary. The

"spelter," which is really only finely granulated fusible brass, is

used for brazing iron joints. The silver solder is convenient for

most purposes where permanency is required, and is especially suited

to the joining of small objects.

§ 93. Soft tinman's solder is made by melting together two parts of

grain tin and one of soft lead--the exact proportions are not of

consequence--but, on the other hand, the purer the constituents the

better the solder. Within certain limits, the greater the proportion

of tin the cleaner and more fusible is the solder. It is usually

worth while to prepare the solder in the laboratory, for in this way a

uniform and dependable product is assured. Good soft lead is melted

in an iron ladle and skimmed; the temperature is allowed to rise very

little above the melting-point. The tin is then added little by

little, the alloy stirred vigorously and skimmed, and sticks of solder

conveniently cast by sweeping the ladle over a clean iron plate, so as

to pour out a thin stream of solder. If the solder be properly made

it will have a mat and bright mottled surface, and will "crackle" when

held up to the ear and bent.

Perhaps the chief precaution necessary in making solder is to exclude

zinc. The presence of a very small percentage of this metal entirely

spoils the solder for tinman's work by preventing its "running" or

flowing smoothly under the soldering bit.

Fig. 75.

Fig. 76.

Fig. 77.

§ 94. Preparing a Soldering Bit.

The wedge-shaped edge of one of the forms of bit shown in the sketch

is filed to shape and the bit heated in a fire or on a gas heater. A

bit of rough sandstone, or even a clean soft brick, or a bit of tin

plate having some sand sprinkled over it, is placed in a convenient

position and sprinkled with resin.

As soon as the bit is hot enough to melt solder it is withdrawn and a

few drops of solder melted on to the brick or its equivalent. The

iron or bit is then rubbed to and fro over the solder and resin till

the former adheres to and tins the copper head. It will be found

advisable to tin every side of the point of the bit and to carry the

tinning back at least half an inch from the edge.

If the solder obstinately refuses to adhere, the cause is to be sought

in the oxidation of the copper, or of the solder, or both--in either

case the result of too high a temperature or too prolonged heating.

The simple remedy is to get the iron hot, and then to dress it with an

old file, so as to expose a bright surface, which is instantly passed

over the resin as a means of preserving it from oxidation. If the

process above described be now carried out, it will be found that the

difficulty disappears.

Before using the iron, wipe off any soot or coke or burned resin by

means of an old rag. An iron tinned in this way is much to be

preferred to one tinned by means of chloride of zinc.

A shorter and more usual method is carried out as follows: The

solution of chloride of zinc is prepared by adding bits of zinc to

some commercial hydrochloric acid diluted with a little (say 25 per

cent) of water. The acid may conveniently be placed in a small glazed

white jar (a jam pot does excellently), and this should only be filled

to about one-quarter of its capacity. An excess of zinc may be added.

It may be fancy, but I prefer a soldering solution made in this way to

a solution of chloride of zinc bought as a chemical product. The jar

is generally mounted on a heavy leaden base, so as to avoid any danger

of its getting knocked over, for nothing is so nasty or bad for tools

as a bench on which this noxious liquid has been upset (Fig. 78).

Fig. 78.

To tin a soldering bit, a little of the fluid is dipped out of the jar

on to a bit of tin plate bent up at the edges--a few drops is

sufficient--and the iron is heated and rubbed about in the liquid

with a drop of solder. If the iron is anything like clean it will tin

at once and exhibit a very bright surface, but quite dirty copper may

be tinned by dipping it for a moment in the liquid in the pot and then

working it about over the solder. An iron so tinned remains covered

with chloride of zinc, and this must be carefully wiped off if it is

intended to use the iron with a resin or tallow flux in lead

soldering.

One disadvantage of this process is that the copper bit soon gets

eaten into holes and requires to be dressed up afresh. On the other

hand, an iron so tinned always presents a nice clean solder surface

until the next time it is heated, when it generally becomes very dirty

and requires to be carefully wiped before using.

In my experience also an iron so tinned is more easily spoiled as to

the state of its surface, "detinned," in fact, by overheating than

when the tinning is carried out by resin and friction. When this

happens, the shortest way out of the difficulty is the application of

the old file so as to obtain a perfectly fresh surface. No one who

knows his business ever uses an iron that is not perfectly clean and

well tinned.

The iron may be cleaned from time to time by heating it red hot and

quenching it in water to get rid of the oxide, which scales off in the

process.

§ 95. Soft Soldering.

In the laboratory the chief application of the process is to copper

soldering during the construction of electrical apparatus and to zinc

soldering for general purposes.

In ninety-nine cases out of every hundred where difficulties occur

their origin is to be traced to dirt. There seems to be some

inexplicable kink in the human mind which renders it callous to

repeated proofs of the necessity for cleaning surfaces which it is

intended to solder. The slightest trace of albuminous or gelatinous

matter or shellac will prevent solder adhering to most metals and the

same remark applies in a measure to the presence of oxides, although

these may be removed by chloride of zinc or prevented from forming by

resin or tallow. A touch with an ordinarily dirty hand--I refer to a

solderer's hand--will often soil work sufficiently to make the

adherence of solder difficult.

The fluxes most generally employed are tallow for lead, resin or

Venice turpentine for copper, chloride of zinc for anything except

lead, which never requires it. The latter flux has the property (also

possessed by borax at a red heat) of dissolving any traces of oxide

which may be formed, as well as acting as a protecting layer to the

metal.

We may now turn to the consideration of a simple case of soldering,

say the joining of two copper wires. The wires are first cleaned

either by dipping in a bath of sulphuric and nitric acids--a thing no

laboratory should be without--or by any suitable mechanical means.

The cleaned wires are then twisted together--there is a regulation

way of doing this, but it presents no advantage in laboratory

practice--and the joint is sprinkled over with resin, or painted

with a solution of resin in alcohol.

The iron, being heated and floated with solder, is held against the

joint, the latter being supported on a brick, and the solder is

allowed to "sweat" into the joint. Enough solder must be present to

penetrate right through the joint. Nothing is gained by rubbing

violently with the iron. If the copper is clean it will tin, and if

it is dirty it won't, and there the matter ends.

Beginners generally use too small or too cold a bit, and produce a

ragged, dirty joint in consequence. If the saving of time be an

object, the joint may be twisted together on ordinarily dirty oxidised

wires and heated to, say, 200° C. It is then painted with chloride of

zinc and soldered with the bit.

There is a difference of opinion as to the relative merits of chloride

of zinc and of resin as a flux in soldering copper. Thus the standing

German practice is, or was, to employ the former flux in every case

for soldering electric light wires, while in England the custom used

to be to specify that soldering should be done by resin, and this

custom may still prevail; it lingers in Australia at all events.

However, it is agreed on all hands that when chloride of zinc is used

it must be carefully washed off. I have known of an electrical

engineer insisting on his workmen "licking" joints with their tongues

to ensure the total removal of chloride of zinc; it has a horrible

taste; and I have occasionally pursued the same plan myself when the

soldering of fine wires was in question.

In any case, it is very certain that chloride of zinc left in a joint

will ruin it sooner or later by loosening the contact between copper

and solder.

Very often it is requisite to solder together two extensive flat

surfaces--for instance, in "chucking" certain kinds of brass work.

The surfaces to be soldered must be carefully tinned, most

conveniently by the help of the blow-pipe and chloride of zinc. After

tinning, the surfaces are laid together and heated so as to "sweat"

them together; the phrase, though inelegant, is expressive.

96. Soldering Tin Plate.

If the plate be new and clean, a little resin or its solution in

alcohol is all that is necessary as a flux. If the tin plate is rusty

the rust must be removed and the clean iron, or rather mild steel,

surface exposed. The use of chloride of zinc is practically essential

in this case. Tin plate is often spotted with rust long before it

becomes rusty as a whole, when, of course, it may be regarded as worn

out, and such rust spots are most conveniently removed by means of the

plumber's shave-hook. The shave-hook is merely a peculiarly shaped

hard steel scraping knife on a handle (Fig. 79).

Fig. 79

With tin plate the soldering of long joints is often necessary. The

plate must be temporarily held in position either by binding with iron

wire, fastening by clamps, or holding by an assistant. The flux is

applied and the iron run slowly along the joint. Enough solder is

used to completely float the tip of the iron. By arranging the joint

so that it slopes downward slightly, and commencing at the upper end,

the solder may be caused to flow after the iron, and will leave a

joint with the minimum permissible amount of solder in it. By

regulating the slope, heat of iron, etc, any desired quantity of

solder may be run into the joint.

§ 97. Soldering Zinc.

Zinc alloys with soft solder very easily, and by so doing entirely

spoils it, making, it "crumbly," dirty, and preventing it running.

Consequently, in soldering up zinc great care must be taken to prevent

the solder becoming appreciably contaminated by the zinc. To this end

the zinc surfaces are cleaned by means of a little hydrochloric acid,

which is painted on instead of chloride of zinc. Plenty of solder is

melted on to the work, and is drawn along over the joint by a single

slow motion of the soldering bit. The iron must be just hot enough to

make the solder flow freely, and it must never be rubbed violently on

the zinc or allowed to linger in one spot; the result of the latter

action will be to melt a hole through the zinc, owing to the tendency

of this metal to form an easily fusible alloy with the solder.

The art of soldering zinc is a very useful one in the laboratory. The

majority of physicists appear to overlook the advantages of zinc

considered as a material for apparatus construction. It is light,

fairly strong, cheap, easily fusible, and yet hard and elastic when

cold. It may be worked as easily as lead at a temperature of, say,

150° to 200° C, and slightly below the melting-point (423° C.) it is

brittle and may & powdered. The property of softening at a moderate

temperature is invaluable as a means of flattening zinc plate or

shaping it in any way. During the work it may be held by means of an

old cloth. Zinc sheet which has been heated between iron plates and

flattened by pressure retains its flatness very fairly well after

cooling.

§ 98. Soldering other Metals.

Iron.

The iron must be filed clean and then brushed with chloride of zinc

solution. Some people add a little sat ammoniac to the chloride of

zinc, but the improvement thus made is practically inappreciable. If

the iron is clean it tins quite easily, and the process of soldering

it is perfectly easy and requires no special comment.

Brass.

The same method as described for iron succeeds perfectly. The brass,

if not exceedingly dirty, may be cleaned by heating to the temperature

at which solder melts (below 200° C.), and painting it over with

chloride of zinc, or dipping it in the liquor. If now the brass be

heated again in the blow-pipe flame, it will be found to tin perfectly

well when rubbed over with solder.

German Silver, Platinoid, Silver, and Platinum are treated like iron.

With regard to silver and platinum the same precautions as recommended

in the case of zinc must be observed, for both these metals form

fusible alloys with solder.

Gold when pure requires no flux. Standard gold, which contains copper,

solders better with a little chloride of zinc.

Lead must be pared absolutely clean and then soldered quickly with a

hot iron, using tallow as a flux. Since solder if over hot will

adhere to lead almost anywhere, plumbers are in the habit of specially

soiling those parts to which it is not intended that solder shall

adhere. The "soiling" paint consists of very thin glue, called size,

mixed with lampblack; on an emergency a raw potato may be cut in half,

and the work to be soiled may be rubbed over with the cut surface of

the potato.

Hard Carbon or gas coke may be soldered after coating with copper by

an electrolytic process, as will be described.

§ 99. Brazing.

Soldering at a red heat by means of spelter is called brazing.

Spelter is soft brass, and is generally made from zinc one part,

copper one part; an alloy easily granulated at a red heat; it is

purchased in the granular form.

The art of brazing is applied to metals which will withstand a red

heat, and the joints so soldered have the strength of brass.

The pieces to be jointed by this method must be carefully cleaned and

held in their proper relative positions by means of iron wire. It is

generally necessary to soften iron wire as purchased by heating it red

hot and allowing it to cool in the air; if this is not done the wire

is usually too hard to be employed satisfactorily for binding.

Very thin wire--i.e. above No. 20 on the Birmingham wire gauge--does

not do, for it gets burned through, and perhaps allows the work

to fall apart at a critical moment.

The work being securely fastened, the next step is to cover the

cleaned parts with flux in order to prevent oxidation. For this

purpose "glass borax" is employed. "Glass" borax is simply ordinary

borax which has been fused for the purpose of getting rid of water of

crystallisation. The glass borax is reduced to powder in an iron

mortar, for it is very hard, and is then made up into a cream with a

little water. This cream is painted on to the parts of the work which

are destined to receive the solder.

The next step is to prepare the spelter, and this is easily done by

mixing it with the cream, taking care to stir thoroughly with a

flattened iron wire till each particle of spelter is perfectly covered

with the borax. The mixture should not be too wet to behave as a

granular mass, and may then be lifted on to the work by means of the

iron spatula.

Care must be taken to place the spelter on those parts only which are

intended to receive it, and when this is done, the joint may be

lightly powdered over with the dry borax, and will then be ready for

heating.

If the object is of considerable size it is most conveniently heated

on the forge; if small the blowpipe is more convenient. In the

latter case, place the work on a firebrick, and arrange two other

bricks on edge about it, so that it lies more or less in a corner. A

few bits of coke may also be placed on and about the work to increase

the temperature by their combustion, and to concentrate the flame and

prevent radiation. The temperature is gradually raised to a bright

red heat, when the spelter will be observed to fuse or "run," as it is

technically said to do.

If the cleaning and distribution of flux has been successful, the

spelter will "run" along the joint very freely, and the work should be

tapped gently to make sure that the spelter has really run into the

joint. The heating may be interrupted when the spelter is observed to

have melted into a continuous mass. As soon as the work has fallen

below a red heat it may be plunged into water, a process which has the

effect of cracking off the glass-like layer of borax.

There is, however, some risk of causing the work to buckle by this

violent treatment, which must of course be modified so as to suit the

circumstances of the case. If the joint is in such a position that

the borax cannot be filed off, a very convenient instrument for its

removal by scraping is the watchmaker's graver, a square rod of hard

steel ground to a bevelled point (Fig. 80).

Fig. 80.

Several precautions require to be mentioned. In the first place,

spelter is merely rather soft brass, and consequently it often cannot

be fused without endangering the rest of the work. A good protection

is a layer of fireclay laid upon the more delicate parts, such for

instance as any screwed part.

Gun-metal and tap-metal do not lend themselves to brazing so readily

as iron or yellow brass, and are usually more conveniently treated by

means of silver solder.

Spelter tends to run very freely when it melts, and if the brass

surface in the neighbourhood of the joint is at all clean, may run

where it is not wanted. Of course some control may be exercised by

"soiling" with fireclay or using an oxidising flame; but the erratic

behaviour of spelter in this respect is the greatest drawback to its

use in apparatus construction. The secret of success in brazing lies

in properly cleaning up the work to begin with, and in disposing the

borax so as to prevent subsequent oxidation.

§ 100. Silver Soldering.

This process resembles that last described, but instead of spelter an

alloy of silver, copper, and zinc is employed. The solder, as

prepared by jewellers to meet special cases, varies a good deal in

composition, but for the laboratory the usual proportions are:

For soft silver solder

Fine silver 2 parts

Brass wire 1 part

For hard silver solder

Sterling silver 3 parts

Brass wire 1 part

The latter is, perhaps, generally the more convenient.

Silver solders may, of course, be purchased at watchmakers' supply

shops, and as thus obtained, are generally in thin sheet. This is

snipped fine with a pair of shears preparatory to use.

As odds and ends of silver (from old anodes and silver residues)

generally accumulate in the laboratory, it is often more convenient to

make the solder one's self. In this case it must be remembered in

making hard solder by the second receipt that standard silver contains

about one-twelfth of its weight of copper--exactly 18 parts copper to

220 silver.

The silver is first melted in a plumbago crucible in a small furnace

together with a little borax; if any copper is required this is then

added, and finally the brass is introduced. When fusion is complete,

the contents of the crucible are poured into any suitable mould.

The quickest and most convenient way of preparing the alloy for use is

to convert it into filings with the assistance of a coarse file, or by

milling it, if a milling machine is available.

Equal volumes of filings and powdered glass borax are made into a thin

paste with water, and applied in an exactly similar manner to that

described under the head of "brazing." In fact all the processes

there described may be applied equally to the case under discussion,

the substitution of silver for spelter being the only variation.

The silver solder is more manageable than spelter, and does not tend

to run wild over the work: a property which makes it much more

convenient both for delicate joints and in cases where it is desired

to restrict the solder to a single point or line. Small objects are

almost invariably soldered with silver solder, and are held by forceps

or on charcoal in the pointed flame of an ordinary blow-pipe.

§ 101. On the Construction of Electrical Apparatus: Insulators.

It is not intended to deal in any way with the design of special

examples of electrical apparatus, but merely to describe a rather

miscellaneous set of materials and processes constantly required in

its construction.

It is not known whether there is such a thing as a perfect insulator,

even if we presuppose ideal circumstances. Materials as they exist

must be regarded merely as of high specific resistance, that is if we

allow ourselves to use such a term in connection with substances,

conduction through which is neither independent of electromotive force

per unit length, nor of previous history.

Even the best of these substances generally get coated with a layer of

moisture when exposed to the air, and this as a rule conducts fairly

well. Very pure crystalline sulphur and fused quartz suffer from this

defect less than any other substances with which the writer is

acquainted, but even with them the surface conductivity soon grows to

such an extent as totally to mask the internal conduction.

It is proposed to give a brief account of the properties of some

insulating substances and their application in electrical

construction, and at the same time to indicate the appliances and

methods requisite for working them.

With regard to the specific resistances which will be quoted, the

numbers must not be taken to mean too much, partly for the reason

already given. It is also in general doubtful whether sufficient care

has been taken to distinguish the body from the surface conductivity,

and consequently numerical estimates are to be regarded with

suspicion. The question of "sampling" also arises, for it must be

remembered that a change in composition amounting to, say, 1/10000 per

cent may be accompanied by a million-fold change in specific

resistance.

§ 102. Sulphur.

This element exists in several allotropic forms, which have very

different electric properties. After melting at about 125° C, and

annealing at 110° for several hours, the soluble crystalline

modification is formed. After keeping for some days--especially if

exposed to light--the crystals lose their optical properties, but

remain of the same melting-point, and are perfectly soluble in carbon

bisulphide. The change is accompanied by a change in colour, or

rather in brightness, as the transparency changes.

The "specific resistance" of sulphur in this condition is above 1028

C.G.S.E.M. units, or 1013 megohms per cubic centimetre for an electric

intensity of say 12,000 volts per centimetre. This is at ordinary

temperatures. At 75° C. the specific resistance falls to about 1025

under similar conditions as to voltage.

In all cases the conductivity appears to increase with the electric

intensity, or at all events with an increase in voltage, the thickness

of the layer of sulphur remaining the same.

The specific inductive capacity is 3.162 at ordinary temperatures, and

increases very slightly with rise of temperature. [Footnote: March

1897.--It is now the opinion of the writer that though the specific

inductive capacity of a given sample of a solid element is perfectly

definite, yet it is very difficult to obtain two samples having

exactly the same value for this constant, even in the case of a

material so well defined as sulphur.]

The total residual charge, after ten minutes' charging with an

intensity of 12,000 volts per centimetre, is not more than 4 parts in

10,000 of the original charge. In making this measurement the

discharge occupied a fraction of a second. The electric strength for

a homogeneous plate of crystalline sulphur is not less than 33,000

volts per centimetre, and probably a good deal more. If the sulphur

is contaminated with up to 3 per cent of the amorphous variety, as is

the case if it is cooled fairly quickly from a temperature of 170° C.

or over, the specific resistance falls to from 10^25 to 10^26 at

ordinary temperatures; and the specific inductive capacity increases

up to 3.75, according to the amount of insoluble sulphur present.

The residual charge under circumstances similar to those described

above, but with an intensity of about 4000 volts per centimetre is,

say, 2 per cent of the initial charge. So far as the writer is aware

sulphur is the only solid non-conductor which can be easily obtained

in a condition of approximate purity and in samples sufficiently

exactly comparable with one another; it is the only one, therefore,

that repays any detail of description.

Very pure sulphur can be bought by the ton if necessary from the

United Alkali Company of Newcastle-on-Tyne. It is recovered from

sulphur waste by the Chance process, which consists in converting the

sulphur into hydrogen sulphide, and burning the latter with

insufficient air for complete combustion. The sulphur is thrown out

of combination, and forms a crystalline mass on the walls and floor of

the chamber.

The sulphur which comes into the market consists of this mass broken

up into convenient fragments. In order to purify it sufficiently for

use as an insulator, the sulphur may be melted at a temperature of

120° to 140° C, and filtered through a plug of glass wool in a zinc

funnel; as thus prepared it is an excellent insulator. To obtain the

results mentioned in the table it is, however, necessary to conduct a

further purification (chiefly from water) by distillation in a glass

retort.

The sulphur thus obtained may be cast of any desired form in zinc

moulds, the castings and moulds being immediately removed to an

annealing oven at a temperature of from 100° to 110° C, where they

are left for several hours. If the sulphur is kept melted for some

time at 125° C. the annealing is not so important.

The castings may be removed from the mould by slightly heating the

latter, but many breakages result. Insulators made on this plan are

much less affected by the condensation of moisture from the air than

anything except fused quartz. They are, however, very weak

mechanically, and apt to crack by exposure to such changes of

temperature as go on from day to day. It is clear, however, that in

spite of this their magnificent electrical properties fit them for

many important uses.

If the sulphur be cooled rapidly from 170° C. or over, a mixture of

the crystalline and amorphous varieties of sulphur is obtained. This

mixture is very much stronger and tougher than the purely crystalline

substance, and may be worked with ordinary hardwood tools into fairly

permanent plates, rods, etc. Sheets of pure thick filter paper may

also be dipped into sulphur at 170° C, at which temperature air and

moisture are mostly expelled, and such sheets show a very considerable

insulating power. The sulphur does not penetrate the paper, which

therefore merely forms a nucleus.

Cakes of the crystalline or mixed varieties may be made by grinding up

some purified sulphur, moistening it with redistilled carbon

bisulphide, or toluene, or even benzene (C6H6), and pressing it in a

suitable mould under the hydraulic press. The plates thus formed are

porous, but are splendid insulators, especially if made from the

crystalline variety of sulphur, and they appear to keep their shape

very well, and do not crack with ordinary temperature changes.

The metals which resist the action of sulphur best are gold and

aluminium; while platinum and zinc are practically unacted upon at

temperatures below a red heat--in the former case,--and below the

boiling-point of sulphur in the latter.

A very convenient test of the purity of sulphur is the colour assumed

by it when suddenly cooled from the temperature at which it is

viscous. Quite pure sulphur remains of a pale lemon yellow under this

treatment, but the slightest trace of impurity, such as arises from

dust containing organic matter, stains the sulphur, and renders it

darker in colour.

§ 103. Fused Quartz.

This is on the whole the most reliable and most perfect insulator for

general purposes. No exact numerical data have been obtained, but the

resistivity must certainly be of the same order as that of pure

sulphur at its best. The influence of the moisture of the air also

reaches its minimum in the case of quartz, as was originally observed

by Boys.

As yet, however, the material can only be obtained in the form of rods

or threads. For most purposes rods of about one-eighth of an inch in

diameter are the most convenient. These rods may be used as

insulating supports, and succeed perfectly even if they interpose less

than an inch of their length to electrical conduction. The sketch

(Figs. 81 and 81A) shows (to a scale of about one-quarter full size)

a complete outfit for elementary electrostatic experiments, such as

has been in use in the writer's laboratory for five years. With these

appliances all the fundamental experiments may be performed, and the

apparatus is always ready at a moment's notice.

Fig. 81.

Though quartz does not condense moisture or gas to form a conducting

layer of anything like the same conductivity as in the case of glass

or ebonite, still it is well to heat it if the best results are to be

obtained. For this purpose a small pointed blow-pipe flame may be

used, and the rods may be got red-hot without the slightest danger of

breaking them. They then remain perfectly good and satisfactory for

several hours at least, even when exposed to damp and dusty air.

The rods are conveniently held in position by small brass ferrules,

into which they are fastened by a little plaster of Paris. Sealing-wax

must be avoided, on account of the inconvenience it causes when the

heating of the rods is being carried out.

One useful application of fused quartz is to the insulation of

galvanometer coils (Fig. 82), another to the manufacture of highly

insulating keys (Fig. 83); while as an insulating suspension it has

all the virtues. If it is desired to render the threads conducting

they may be lightly silvered, and will be found to conduct well enough

for electrometer work before the silver coating is thick enough to

sensibly impair their elastic properties.

Fig. 81A.

Fig. 82 is a full-size working drawing of a particular form of

mounting for galvanometer coils. The objects sought to be attained

are:

(1) high insulation of the coils,

(2) easy adjustment of the coils to the suspended system.

The first object is attained as follows. The ebonite ring A is bored

with four radial holes, through which are slipped from the inside the

fused quartz bolt-headed pins B. The coil already soaked in hard

paraffin is placed concentrically in the ring A by means of a special

temporary centering stand. The space between the coil and the ring is

filled up with hard paraffin, and this holds the quartz pins in

position. The system of ebonite ring, coil, and pins is then fastened

into the gun-metal coil carrier, which is cut away entirely, except

near the edges, where it carries the pin brackets C. These brackets

can swivel about the lower fastening at E before the latter is

tightened up.

The coil is now adjusted in the adjusting stand to be concentric with

the axis of symmetry of the coil carrier, and the supporting pins are

slipped into slot holes cut in the brackets, the brackets being

swivelled as much as necessary to allow of this. When the pins are

all inserted the brackets are screwed up by the screws at E. The pins

are then cemented firmly to the brackets by a little plaster of Paris.

The coil carrier can now be adjusted to the galvanometer frame by

means of screws at D, which pass through wide holes in the carrier and

bold the latter in position by their heads. In the sectional plan the

parts of the galvanometer frame are shown shaded. The front of the

frame at F F is of glass, and the back of the frame is also made of

glass, though this is not shown in the section.

A represents an ebonite ring into which the wire coil is cemented by

means of paraffin. B B B B are quartz pins, with heads inside the

ebonite ring. C C C are slotted brackets adjustable to the pins and

capable of rotation by releasing the screws E E. D D are the screws

holding the coil carriage to the galvanometer framework. These screws

pass through large holes in the carriage so as to allow of some

adjustment.

Fig. 82.

Fig. 83.

§ 104. Glass.

When glass is properly chosen and perfectly dry it has insulating

properties possibly equal to those possessed by quartz or crystalline

sulphur. For many purposes, however, its usefulness is seriously

reduced by the persistence with which it exhibits the phenomena of

residual charge, and the difficulty that is experienced in keeping it

dry.

The insulating power of white flint glass is much in excess of that of

soft soda glass, which is a poor insulator, and of ordinary green

bottle glass. The jars of Lord Kelvin's electrometers, which insulate

very well, are made of white flint glass manufactured in Glasgow, but

it is found that occasionally a particular jar has to be rejected on

account of its refusing to insulate, and this, if I understand aright,

even when it exhibits no visible defects.

A large number of varieties of glass were tested by Dr. Hopkinson at

Messrs. Chance Bros. Works, in 1875 and 1876 (Phil. Trans, 1877),

and in 1887 (Proc. Roy. Soc. xli. 453), chiefly with a view to the

elucidation of the laws regulating the residual charge; and

incidentally some extraordinarily high insulations were noted among

the flint glasses. The glass which gave the smallest residual charge

was an "opal" glass; and flint glasses were found to insulate 105

times as well as soda lime glasses. The plates of Wimshurst machines

are made of ordinary sheet window glass, but as the insulating

property of this material appears to vary, it is generally necessary

to clean, dry, and test a sheet before using it. With regard to hard

Bohemian glass, this is stated by Koeller (Wien Bericht) to insulate

ten times as well as the ordinary Thuringian soft soda glass.

On the whole the most satisfactory laboratory practice is to employ

good white flint glass. The only point requiring attention is the

preparation of the glass by cleaning and drying. Of course all grease

or visible dirt must be removed as described in an earlier chapter (§

13), but this is only a beginning. The glass after being treated as

described and got into such a state as to its surface that clean water

no longer tends to dry off unequally, must be subjected to a further

scrub with bibulous paper and a clear solution of oleate of soda. The

glass is then to be well rinsed with distilled water and allowed to

drain on a sheet of filter paper.

A very common cause of failure lies in the contamination of the glass

with grease from the operator's fingers. Before setting out to clean

the glass the student will do well to wash his hands with soap and

water, then with dilute ammonia and finally with distilled water.

In the case of an electrometer jar which has become conducting but is

not perceptibly dirty, rubbing with a little oleate of soda and a silk

ribbon, followed, of course, by copious washing, does very well. If

there is any tin-foil on the jar, great care must be taken not to

allow the glass surface to become contaminated by the shellac varnish

or gum used to stick the tin-foil in position.

Finally, the glass should be dried by radiant heat and raised to a

temperature of 100° C. at least, and kept at it for at least half an

hour. Before drying it is of course advisable to allow the water to

drain away as far as possible, and if the water is only the ordinary

distilled water of the laboratory, the glass is preferably wiped with

a clean bit of filter paper; any hairs which may be left upon the

glass will brush off easily when the glass is dry.

In order to obtain satisfactory results the glass must be placed in

dry air before it has appreciably cooled. This is easily done in the

case of electrometer jars, and so long as the air remains perfectly

dry through the action of sulphuric acid or phosphorus pentoxide, the

jar will insulate. The slightest whiff of ordinarily damp air will,

however, enormously reduce the insulating power of the glass, so that

unvarnished glass surfaces must be kept for apparatus which is

practically air-tight.

For outside or imperfectly protected uses the glass does better when

varnished. It is a fact, however, that varnished glass is rarely if

ever so good as unvarnished glass at its best. Too much care cannot

be taken over the preparation of the varnish; French polish, or

carelessly made shellac varnish, is likely to do more harm than good.

The best orange shellac must be dissolved in good cold alcohol by

shaking the materials together in a bottle. The alcohol is made

sufficiently pure by starting with rectified spirit and digesting it

in a tin flask over quick-lime for several days, a reversed condenser

being attached. A large excess of lime must be employed, and this

leads to a considerable loss of alcohol, a misfortune which must be

put up with.

After, say, thirty hours' digestion, the alcohol may be distilled off

and employed to act on the shellac. In making varnish, time and

trouble are saved by making a good deal at one operation--a

Winchester full is a reasonable quantity. The bottle may be filled

three-quarters full of the shellac flakes and then filled up with

alcohol; this gives a solution of a convenient strength.

The solution, however, is by no means perfect, for the shellac

contains insoluble matter, and this must be got rid off.`' One way of

doing this is to filter the solution through the thick filtering paper

made by Schleicher and Schuell for the purpose, but the filtering is a

slow process, and hence requires to be conducted by a filter paper

held in a clip (not a funnel) under a bell jar to avoid evaporation.

Another and generally more convenient way in the laboratory is to

allow the muddy varnish to settle--a process requiring at least a

month--and to decant the clear solution off into another bottle,

where it is kept for use. The muddy residue works up with the next

lot of shellac and alcohol, which may be added at once for future use.

The glass to be varnished is warmed to a temperature of, say, 50° C,

and the varnish put on with a lacquering brush; a thin uniform coat is

required. The glass is left to dry long enough for the shellac to get

nearly hard and to allow most of the alcohol to evaporate. It is then

heated before a fire, or even over a Bunsen, till the shellac softens

and begins to yield its fragrant characteristic smell.

If the coating is too heavy, or if the heating is commenced before the

shellac is sufficiently dry, the latter will draw up into "tears,"

which are unsightly and difficult to dry properly. On no account must

the shellac be allowed to get overheated. If the varnish is not quite

hard when cold it may be assumed to be doing more harm than good.

In varnishing glass tubes for insulating purposes it must be

remembered that the inside of the tube is seldom closed perfectly as

against the external air, and consequently it also requires to be

varnished. This is best done by pouring in a little varnish

considerably more dilute than that described, and allowing it to drain

away as far as possible, after seeing that it has flooded every part

of the tube.

During this part of the process the upper end of the tube must be

closed, or evaporation will go on so fast that moisture will be

deposited from the air upon the varnished surface. Afterwards the

tube may be gently warmed and a current of air allowed to pass, so as

to prevent alcohol distilling from one part of the tube to another.

The tube is finally heated to the softening point of shellac, and if

possible closed as far as is practicable at once.

§ 105. Ebonite or Hard Rubber.

This exceedingly useful substance can be bought of a perfectly useless

quality. Much of the ebonite formerly used to cover induction coils

for instance, deteriorates so rapidly when exposed to the air that it

requires to have its surface renewed every few weeks.

The very best quality of ebonite obtainable should be solely employed

in constructing electric works. It is possible to purchase good

ebonite from the Silvertown Rubber Company (and probably from other

firms), but the price is necessarily high, about four shillings per

pound or over.

At ordinary temperatures ebonite is hard and brittle and breaks with a

well-marked conchoidal fracture. At the temperature of boiling water

the ebonite becomes somewhat softened, so that it is readily bent into

any desired shape; on cooling it resumes its original hardness.

This property of softening at the temperature of boiling water is a

very valuable one. The ebonite to be bent or flattened is merely

boiled for half an hour or so in water, taken out, brought to the

required shape as quickly as possible, and left to cool clamped in

position.

The sheet ebonite as it comes from the makers is generally far from

flat. It is often necessary to flatten a sheet of ebonite, and of

course this is the more easily accomplished the smaller the sheet.

Consequently a bit of ebonite of about the required size is first cut

from the stock sheet by a hack-saw such as is generally used for

metals. This piece is then boiled and pressed between two planed iron

plates previously warmed to near 100° C.

With pieces of ebonite such as are used for the tops of resistance

boxes, measuring, say, 20 X 8 X 11 inches, very little trouble is

experienced. The sheets when cold are found to retain the flatness

which has been forced upon them perfectly well. It is otherwise with

large thin sheets such as are used for Holtz machines. I have

succeeded fairly, but only fairly, by pressing them in a "gluing

press," consisting of heavy planed iron slabs previously heated to

100° C.

I do not know exactly how best to flatten very thin and large sheets.

It is easy to make large tubes out of sheet ebonite by taking

advantage of the softening which ebonite undergoes in boiling water.

A wooden mandrel is prepared of the proper size and shape. The

ebonite is softened and bent round it; this may require two or three

operations, for the ebonite gets stiff very quickly after it is taken

out of the water. Finally the tube is bound round the mandrel with

sufficient force to bring it to the proper shape and boiled in water,

mandrel and all. The bath and its contents are allowed to cool

together, so that the ebonite cools uniformly.

Tubes made in this way are of course subject to the drawback of having

an unwelded seam, but they do well enough to wind wire upon if very

great accuracy of form is not required. If very accurate spools are

needed the mandrel is better made of iron or slate and the spool is

turned up afterwards. The seam may be strapped inside or at the ends

by bits of ebonite acting as bridges, and the seam itself may be

caulked with melted paraffin or anthracene.

Working Ebonite.

Ebonite is best worked as if it were brass, with ordinary

brass-turning or planing tools. These tools should be as hard as

possible, for the edges are apt to suffer severely, and blunt tools

leave a very undesirable woolly surface on the ebonite. In turning or

shaping ebonite sheets it is as well to begin by taking the skin off

one side first, and then reversing the sheet, finishing the second

side, and then returning to the first. This is on account of the fact

that ebonite sometimes springs a little out of shape when the skin is

removed.

Turned work in ebonite, if well done, requires no sand-papering, but

may be sufficiently polished by a handful of its own shavings and a

little vaseline. The advantage of using a polished ebonite surface is

that such a surface deteriorates more slowly under the influence of

light and air than a surface left rough from the tool. If very highly

polished surfaces are required, the ebonite after tooling is worked

with fine pumice dust and water, applied on felt, or where possible by

means of a felt buff on the lathe, and finally polished with rouge and

water, applied on felt or cloth.

Ebonite works particularly well under a spiral milling cutter, and

sufficiently well under an ordinary rounded planing tool, with cutting

angle the same as for brass, and hardened to the lightest straw

colour.

It is not possible, on the other hand, to use the carpenter's plane

with success, for the angle of the tool is too acute and causes the

ebonite to chip.

In boring ebonite the drill should be withdrawn from the hole pretty

often and well lubricated, for if the borings jam, as they are apt to

do, the heat developed is very great and the temper of the drill gets

spoiled. Ebonite will spoil a drill by heating as quickly as anything

known; on the other hand, it may be drilled very fast if proper

precaution is taken.

It is advisable to expose ebonite to the light as little as possible,

especially if the surface is unpolished, for under the combined action

of light and air the sulphur at the surface of the ebonite rapidly

oxidises, and the ebonite becomes covered with a thin but highly

conducting layer of sulphurous or sulphuric acid or their compounds.

When this happens the ebonite may be improved by scrubbing with hot

water, or washing freely with alcohol rubbed on with cotton waste in

the case of apparatus that cannot be dismounted.

A complete cure, however, can only be effected by scraping off the

outer layer of ebonite so as to expose a fresh surface. For this

purpose a bit of sheet glass broken so as to leave a curved edge is

very useful, and the ebonite is then scraped like a cricket bat. In

designing apparatus for laboratory use it is as well to bear in mind

that sooner or later the ebonite parts will require to be taken down

and scraped up. Rods or tubes are, of course, most quickly treated on

the lathe with rough glass cloth, and may be finished with fine

sandpaper, then pumice dust and water, applied on felt. After

cleaning the pumice off by means of water and a rag, the final touch

may be given by means of vaseline, applied on cloth or on ebonite

shavings.

§ 106. Mica.

A great variety of minerals go under this name. Speaking generally,

the Russian micas coming into commerce are potash micas, and mica

purchased in England may be taken to be potash mica, especially if it

is in large sheets.

At ordinary temperatures "mica" of the kind found in commerce is an

excellent insulator. Schultze (Wied. Ann. vol. xxxvi. p. 655) comes

to the conclusion that both at high and at low temperatures mica (of

all kinds?) is a better insulator than white "mirror glass," the

composition of which is not stated. The experiments of the author

referred to were apparently left unfinished, and altogether too much

stress must not be laid on the results obtained, one of which was that

mica conducts electrolytically to some extent at high temperatures.

Bouty (Journal de Physique, 1890 [9], 288) and J. Curie (Thèse de

Doctorat, Paris, 1888) agree in making the final conductivity of the

mica used in Carpentier's condensers exceedingly small--at all events

at ordinary temperatures. Bearing in mind that for such substances

the term specific resistance has no very definite meaning, M. Bouty

considers it is not less than 3.19 x 1028 E.M. units at ordinary

temperatures. M. Bouty gives a note or illustration of what such

numbers mean--a precaution not superfluous in cases where magnitudes

are denoted logarithmically. Referring to the value quoted, viz.

3.19 x 1028, M. Bouty says, "Ce serait la resistance d'une colonne de

mercure de 1mmq de section et de longueur telle que la lumière se

propageant dans le vide, mettrait plus de 3000 ans A se transmettre

d'une extrémité à I'autre de la colonne."

M. Bouty returns to the study of mica (muscovite) in the Journal de

Physique for 1892, p. 5, and there deals with the specific inductive

capacity, which for a very small period of charge he finds has the

value 8--an enormous value for such a good insulator, and one that it

would be desirable to verify by some totally distinct method. This

remark is enforced by the fact that M. Klemencic finds the number 6

for the same constant. The temperature coefficient of this constant

was too small for M. Bouty to determine. The electric intensity was

of the order of 100 volts per centimetre, and the experiments seem to

indicate that the specific inductive capacity would be only slightly

less if referred to a period of charge indefinitely short.

I have found that the residual charge in a mica condenser, made

according to Carpentier's method (to be described below), is about 1

per cent of the original charge under the following circumstances.

Voltage 300 volts on a plate 0.2 mm. thick, duration of charge ten

minutes, temperature about 20° C. To get this result the mica must be

most carefully dried. This and other facts indicate that the

so-called residual charge on ordinary condensers is, to a very large

extent, due to the creeping of the charge from the armatures over the

more or less conducting varnished surfaces of the mica, and its slow

return on discharge.

This source of residual charge was carefully guarded against by

Rowland and Nichols (Phil. Mag. 1881) in their work on quartz, and is

referred to by M. Bouty, who adduces some experiments to show that his

own results are not vitiated by it. On the other hand, M. Bouty shows

that a small rise in temperature enormously affects the state of a

mica surface, and that the surface gets changed in such a way as to

become very fairly conducting at 300° C. Also anybody can easily try

for himself whether exposing a mica condenser plate which has been

examined in presence of phosphorus pentoxide to ordinary air for five

minutes will not enormously increase the residual charge, as has

always been the case in the writer's experience, and if so, it is open

to him to suggest some cause other than surface creeping as an

explanation.

M. Bouty, using less perfectly dried mica, did not get so good a

result as to smallness of residual charge as the one above quoted.

The chief use of mica for laboratory purposes depends on the ease with

which it can be split, and also upon the fact that it may be

considerably crumpled and bent without breaking. It therefore makes

an excellent dielectric in so far as convenience of construction is

concerned in the preparation of condensers, and lends itself freely to

the construction of insulating washers or separators of any kind. Its

success as a fair insulator at moderate temperatures has led to its

use in resistance thermometers, where it appears to have given

satisfaction up to, at all events, 400° C.

It is worth a note that according to Werner Siemens, who had immense

experience (Wied. Ann. vol. clix.), soapstone is the only reliable

insulator at a red heat, but, no doubt, a good deal depends on the

particular specimen investigated.

§ 107. Use of Mica in Condensers.

If good results are desired it is essential to select the mica very

carefully. Pieces appreciably stained,--particularly if the stain is

not uniformly distributed,--cracked pieces, and pieces tending to

flake off in patches should be rejected. The best samples of mica

that have come under the writer's observation are those sheets sold

for the purpose of giving to silver photographic prints that hideous

glazed surface which some years ago was so popular.

Sheets of mica about 0.1 to 0.2 mm. thick form good serviceable

condenser plates, and will certainly stand a pressure of 300 volts,

and most likely a good deal more. The general practice in England

seems to have been to build up condensers of alternate sheets of

varnished or paraffined-mica and tin-foil.

This practice is open to several objections. In the first place, the

capacity of a condenser made in this way varies with the pressure

binding the plates together. In the second place, the amount of mica

and tin-foil required is often excessive in consequence of the

imperfect contact of these substances. Again, the inevitable air film

between the mica and tin-foil renders condensers so made unsuitable

for use with alternating currents, owing to the heating set up through

air discharges, and which is generally, though often (if not always)

wrongly, attributed to dielectric hysteresis.

These imperfections are to a great extent got over by M. Carpentier's

method of construction, which is, however, rather more costly both in

material and labour. On the other hand, wonderful capacities are

obtained with quite small amounts of mica. M. Bouty mentions a

condenser of one microfarad capacity weighing 1500 grms. and

contained in a square box measuring 12 centimetres on the side, and

about 3 centimetres thick.

The relation between the capacity and surface of doubly-coated plates

is in electro-static units:

Capacity = (sp. ind. capacity X area of one surface)/(4pi X thickness)

This may be reduced to electro-magnetic units by dividing by 9x10^20,

and to microfarads by further multiplying by 10^15.

M. Carpentier begins, of course, by having his mica scrupulously clean

and well selected. It is then silvered by one of the silvering

processes (§ 65) on both sides, for which purpose the sheets may be

suspended in a paraffined wood rack, so as to lie horizontally in the

silvering solution, a space of about half an inch being allowed

between the sheets. The silvering being finished, the sheets are

dipped along two parallel edges in 75 per cent nitric acid. With

regard to the third and fourth edges of the sheet, the silver is

removed on one side only, using a spun glass brush; if we agree to

call the two surfaces of the mica A and B respectively, and the two

edges in question C and D, then the silver is removed from the A side

along edge C, and from the B side along edge D. The silvered part is

shown shaded in Fig. 84. By this arrangement the silver and mica

plates may be built up together so as to form the same mutual

arrangement of contacts as in an ordinary mica tin-foil condenser.

Fig. 84.

It need hardly be said that the sheets require very complete washing

after treatment with nitric acid, followed by a varnishing of the

edges as already described in the case of glass, and baking at a

temperature of 140° C. in air free from flame gases, till the shellac

begins to emit its characteristic odour and is absolutely hard when

cold.

The plates are then built up so as to connect the sheets which require

to be connected, and to insulate the other set. General contact is,

if necessary, secured by means of a little silver leaf looped across

from plate to plate--a part of the construction which requires

particular attention and clean hands, for it is by no means so easy to

make an unimpeachable contact as might at first appear.

The condenser, having been built up, may be clamped solid and placed

in its case; the capacity will not depend appreciably on the

tightness of the clamp screws--a great feature of the construction.

Such a condenser will not give its best results unless absolutely dry.

I have kept one very conveniently in a vacuum desiccator over

phosphorus pentoxide, but if of any size, the condenser deserves a box

to itself, and this must be air-tight and provided with a drying

reagent, so arranged that it can be removed through a manhole of some

sort.

Contact to the brass-work on the lid may be made by pressing spring

contacts tightly down upon the ends of the silver foils and carrying

the connections through the lid. This also serves to secure the

condenser in position.

§ 108. Micanite.

This substance, though probably comparing somewhat unfavourably with

the insulators already enumerated, and being subject to the

uncertainties of manufacture, has during the last few years achieved a

considerable success in American electrical engineering construction.

It is composed of scrap mica and shellac varnish worked under pressure

to the desired shape, and may be obtained in sheets, plates, and rods,

or in any of the forms for which a die happens to have been

constructed.

Of course, in special cases it would be worth while to prepare a die,

and then the attainable forms would be limited by moulding

considerations only. The writer's experience is very limited in this

matter, but Dr. Kennelly, with whom he communicated on the subject,

was good enough to reply in favour of micanite for engineering work.

§ 109. Celluloid.

This material is composed of nitrocellulose and camphor.

It has fair insulating properties, and may be obtained in a variety of

forms, but has now been generally abandoned for electrical work on

account of its inflammability.

§ 110. Paper.

Pure white filter paper, perfectly dry, is probably a very fair

insulator; the misfortune is that in practice it cannot be kept dry.

Under the most favourable circumstances its specific resistance may

approach 1024 E.M. units. It must therefore be considered rather as a

partial conductor than as an insulator. The only case of the use of

dry paper as an insulator in machine construction which has come under

the writer's notice is in building up the commutators of the small

motors which used to drive the Edison phonographs.

Its advantages in this connection are to be traced to the fact that a

commutator so built up is durable and keeps a clean surface. Of

course, the use of paper as an insulator for telephone wires is well

known, but its success in this direction depends less upon its

insulating properties than upon the fact that it can be arranged in

such a way as to allow of the wires being partially air insulated, an

arrangement tending to reduce the electrostatic capacity of the wire

system.

At one time it was the custom of instrument makers to employ ordinary

printed paper in the shape of leaves torn from books or the folios of

old ledgers to form the dielectric of the condensers used in

connection with the contact breakers of induction coils. This

practice has nothing but economy to recommend it, for cases often

occur in which the paper, by gradual absorption of moisture from the

air, comes to insulate so badly that it practically short circuits the

spark gap, and so stops the action of the coil. Three separate cases

have come within the writer's experience.

Some measurements of the resistance of paper have been made by F.

Uppenborn (Centralblatt fuer Electrotechnik, Vol. xi. p. 215,

1889). There is an abstract of the paper also in Wiedemann's

Beiblaetter (1889, vol. xiii. P. 711). Uppenborn examined the

samples of paper under normal conditions as to moisture and obtained

the following results:-

Description of Paper

I

Pressure Intensity

II.

Specific Resistance corresponding to pressures as in Column I. Ohms.

III

Pressure Intensity.

IV.

Specific Resistance corresponding to Column III. Ohms.

Common cardboard 2.3 mm. thick

0.05 kilo. per 6000 sq. mm.

4.85 x 1015

20 kg. per 6000 sq. mm.

4.7 x 1014

Gray paper, 0.26 mm. thick

0.05 kilo. per 5000 sq. mm.

3.1 x 10^15

20 kg. per 5000 sq. mm.

8 x 1014

Yellow parchment paper-09 mm. thick

0.05 kilo. per 5300 sq. mm.

3.05 x 1016

20 kg. per 5300 sq. mm.

8 x 1016

Linen tracing cloth

0.05 kilo. per 6000 sq. mm.

1.35 x 1016

20 kg. per 33,000 sq. mm.

1.86 x 10^15

§ 111. Paraffined Paper.

Like wood and other semiconductors, paper can be vastly improved as an

insulator by saturating it with melted paraffin. To get the best

results a pure paper free from size must be employed--gray Swedish

filter paper does well. This is dried at a temperature above 100° C.

for, say, half an hour, and the sheets are then floated on the top of

paraffin, kept melted at 140° C. or thereabout in a baking dish. As

soon as the paper is placed upon the melted paraffin the latter begins

to soak through, in virtue of capillary action, and drives before it

the air and moisture, causing a strongly marked effervescence.

After about one minute the paper may be thrust below the paraffin to

soak. When a sufficient number of papers have accumulated, and when

no more gas comes off, the tray may be placed in a vacuum box (Fig.

85), and the pressure reduced by the filter pump. As the removal of

the air takes time, provision must be made for keeping the bath hot.

A vacuum may be maintained for about an hour, and air then readmitted.

Repeated exhaustions and readmissions of air, which appear to improve

wood, do not give anything like such a good result with paper. In

using a vacuum box provision must be made in the shape of a cool

bottle between the air pump and the box. If this precaution be

omitted, and if any paraffin splashes on to the hot surface of the

box, it volatilises with decomposition and the products go to stop up

the pump. Paraffin with a melting-point of 50° C. or upwards does

well.

The bath should be allowed to cool to about 60° C. before the papers

are removed, so that enough paraffin may be carried out to thoroughly

coat the paper and prevent the entrance of air.

Fig. 85.

Fig. 85 is a section of a vacuum vessel which has been found very

convenient. It measures about two feet in diameter at the top. It is

round, because it is much easier to turn one circular surface than to

plane up four surfaces, which has to be done if the box is square.

Both the rim of the vessel and the approximating part of the cover

require to be truly turned and smoothly finished. A very good packing

is made of solid indiarubber core about half an inch thick. This is

carefully spliced--cemented by means of a solution of rubber in

naphtha, and the splice sewed by thick thread. The lid ought to have

a rim fitting inside the vessel, for this keeps the rubber packing in

place; the rim has been accidentally omitted in Fig. 85. The bolts

should not be more than five inches apart, and should lie at least

half an inch in diameter, and the rim and lid should be each half an

inch thick.

Condensers may now be built up of sheets of this prepared paper

interleaved with tin-foil in the ordinary way. If good results are

required, the condenser when finished is compressed between wooden or

glass end-pieces by means of suitable clamps. It can then be put in a

box of melted paraffin, heated up to 140° C, and exhausted by means

of the water pump for several hours.

In this process the air rushes out from between the paper and foils

with such vehemence that the paraffin is generally thrown entirely out

of the box. To guard against this the box must be provided with a

loosely fitting and temporary lid, pierced with several holes.

The real test as to when exhaustion is complete would be the cessation

of any yield of air or water. Since it is not generally convenient to

make the vacuum box so air-tight that there are absolutely no leaks at

all, and as the paraffin itself is, I think, inclined to "crack"

slightly at the temperature of 140° C, this test or criterion cannot

be conveniently applied.

Two exhaustions, each of about two hours' duration, have, however, in

my experience succeeded very well, provided, of course, that the

dielectric is prepared as suggested. At the end of the exhaustion

process the clamping screws are tightened as far as possible, the

condenser remaining in its bath until the paraffin is pasty.

Condensers made in this way resist the application of alternating

currents perfectly, as the following tests will show. The dielectric

consisted of about equal parts of hard paraffin and vaseline. A

condenser of about 0.123 microfarads capacity and an insulation

resistance of 2000 megohms, [Footnote: As tested by a small voltage.]

having a tin-foil area of 4.23 square metres (about), and double

papers each about 0.2 mm. thick, designed to run at 2000 volts with a

frequency of 63 complete periods, was tested at this frequency.

The condenser was thoroughly packed all round in cotton-wool to a

thickness of 6 inches, and its temperature was indicated more or less

by a thermometer plunged through a hole in the lid of the containing

box and of the condenser box, and resting on the upper surface of one

set of tin-foil electrodes, from which the soft paraffin mixture had

been purposely scraped away. The following were the results of a four

hours' run at a voltage 50 per cent higher than that for which the

condenser was designed--i.e. 3000 volts.

Times. Voltage Temperature Temperature Difference

in Condenser. in Air.

Hrs. Min.

2 10 2750 22.8° C. 23.0° C. + 0.2°

3 10 2700 23.0° C. 23.3° C. + 0.3°

3 18 3200 23.1° C. 23.0° C. -0.1°

4 10 3200 23.3° C. 23.7° C. + 0.4°

5 10 3100 23.6° C. 23.4° C. -0.2°

6 10 3000 23.8° C. 23.35° C. -0.45°

An idea of the order of the amount of waste may be formed from the

following additional experiment.

A condenser similar to the one described was filled with oil of a low

insulating power. It was tested calorimetrically, and also by the

three voltmeter method, which, however, proved to be too insensitive.

The temperature rise in the non-conducting box in air was about 0.3°

C. per hour, and the loss of power was found to be less than 0.1 per

cent. In the present case the actual rise was only 1° in four hours,

and the integral give and take between the condenser and the air is

practically nothing; consequently we may consider with safety that the

rate of rise is certainly less than 1 degree per three hours. The

voltage and frequency were about the same in both experiments,

consequently the energy passed is about proportional to the capacity

used in the two experiments.

From this it follows that since the specific heat of both condensers

was the same (nearly), the loss in the present case is a good deal

less than one-tenth per cent. The residual charge is also much less

than when the condenser is simply built up of paper paraffined in an

unsystematic manner, and from which the air and water have been

imperfectly extracted, as by baking the condenser first, and then

immersing it in paraffin or oil.

It is usual to consider that the phenomena of residual charge and

heating in condensers, to which alternating voltages are applied, are

closely allied. This is true, but the alliance is not one between

cause and effect--at all events, with regard to the greater part of

the heating. The imperfect exclusion of air and moisture,

particularly the latter, certainly increases the residual charge by

allowing surface creeping to occur; but it also acts directly in

producing heating, both by lowering the insulation of the condenser

and by allowing of air discharges between the condenser plates.

Of these causes of heating, the discharges in air or water vapour are

probably the more important. Long ago a theory of residual charge was

given by Maxwell, based on the consideration of a laminated

dielectric, the inductivity and resistance of which varied from layer

to layer. It was shown that such an arrangement, and hence generally

any want of homogeneity in a direction inclined to the lines of force

leading to a change of value of the product of specific resistance and

specific inductive capacity, would account for residual charge.

This possible explanation has been generally accepted as the actual

explanation, and many cases of residual charge attributed to want of

homogeneity, which are certainly to be explained in a simpler manner.

For instance, the residual charge in a silvered mica plate condenser,

carefully dried, can be increased at least tenfold by an exposure of a

few minutes to ordinarily damp air. The same result occurs with

condensers of paraffined or sulphured paper; and these are the

residual changes generally observed. The greater part must be due to

creeping.

§ 112. Paraffin.

This substance has long enjoyed great popularity in the physical

laboratory. Its specific resistance is given by Ayrton and Perry as

more than 1025, but it is probably much higher in selected samples.

The most serviceable kind of paraffin is the hardest obtainable,

melting at a temperature of not less than 52° C. It is a good plan to

remelt the commercial paraffin and keep it at a temperature of, say,

120° C. for an hour, stirring it carefully with a glass rod so that

it does not get overheated; this helps to get rid of traces of water

vapour.

Hard paraffin, when melted, has an enormous rate of expansion with

temperature, so great, indeed, that care must be taken not to overfill

the vessels in which it is to be heated. Castings can only be

prepared by cooling the mould slowly from the bottom, keeping the rest

of the mould warm, and adding-paraffin from time to time to make up

for the contraction. The cooling is gradually allowed to spread up to

the free surface.

The chief use of paraffin in the laboratory is in the construction of

complicated connection boards, which are easily made by drilling holes

in a slab of paraffin, half filling them with mercury, and using them

as mercury cups.

Since paraffin is a great collector of dust, it should be screened by

paper, otherwise the blocks require to be scraped at frequent

intervals, which, of course, electrifies them considerably. This

electrification is often difficult to remove without injuring the

insulating power of the paraffin. A light touch with a clean Bunsen

flame is the readiest method, and does not appear to reduce the

insulation so much as might be expected. The safest way, however, is

to leave the key covered by a clean cloth, which, however, must not

touch the surface, for a sufficient time to allow of the charges

getting away.

The paraffin often becomes electrified itself by the friction of the

key contacts, so that in electrometer work it is often convenient to

form the cups by lining them with a little roll of copper foil twisted

up at the bottom. In this case the connecting wires should, of course,

be copper. Small steel staples are convenient for fastening the

collecting wires upon the paraffin; or, in the case where these wires

have to be often removed and changed about, drawing-pins are very

handy.

With mercury cups simply bored in paraffin great trouble will often be

experienced in electrometer work, owing to a potential difference

appearing between the cups--at all events when the contacts are

inserted and however carefully this be done. A few drops of very pure

alcohol poured in above the mercury often cures this defect. The

surface of paraffin is by no means exempt from the defect of losing

its insulating power when exposed to damp air, but it is not so

sensitive as glass, nor does the insulating power fall so far.

Two useful appliances are figured.

Fig. 86. Fig. 87.

One, in which paraffin appears as a cement, is an insulating stand

made out of a bit of glass or ebonite tube cemented into an Erlenmeyer

flask, having its neck protected from dust when out of use by a rubber

washer, the other a "petticoat" insulator made by cementing a flint

glass bottle into a glass dish with paraffin. In course of time the

paraffin will be found to have separated from the glass. When this

occurs the apparatus may be melted together again by placing it on

the water bath for a few minutes.

§ 113. Vaseline, Vaseline Oil, and Kerosene Oil.

These, when dry, insulate almost, but not quite as well as solid

paraffin. H. Koeller (Wien Berichte, 98, ii. 201, 1889; Beibl. Wied.

Ann. 1890, p. 186), working with very small voltages, places the

final(?) specific resistance of commercial petroleum, ether, and

vaseline oil at about 2 X 1027 C.G.S. This is ten times higher than

the value assigned to commercial benzene (C6H6), and a hundred times

higher than the value for commercial toluene.

All these numbers mean little or nothing, but the petroleum and

vaseline oil were the best fluid insulators examined by Koeller. By

mixing vaseline with paraffin a soft wax may be made of any desired

degree of softness, and by dissolving vaseline in kerosene an

insulating liquid of any degree of viscidity may be obtained.

Hard paraffin may be softened somewhat by the addition of kerosene,

and an apparently homogeneous mass cast from the mixture. It will be

found, however, that in course of time the kerosene oozes out, unless

present in very small quantity. Koeller has found (loc. cit.) that

some samples of vaseline oil conducted "vollstaendig gut," but I have

not come across such samples. Vaseline oil, however, is sold at a

price much above its value for insulating purposes.

Kerosene oil is best obtained dry by drawing it directly from a new

tin and exposing it to air as little as possible. Of course, it may

be dried by chemical means and distillation, but this is usually (or

always) unnecessary.

Fig 88.

There is some danger of kerosene containing minute traces of sulphuric

acid, and it and other oils may be conveniently tested for insulation

in the following manner. The quartz electroscope is taken, and the

insulating rod heated in the blow-pipe. The electroscope will now

insulate well enough to show no appreciable collapse of the leaves in

one or two hours' time. Upon the plate of the electroscope is put a

platinum or copper cylinder, and this is filled with kerosene (say) up

to a fixed mark.

The electroscope is placed on a surface plate, or, at all events, on a

sheet of plate glass, and a "scribing block" is placed along side it

and the scriber adjusted to dip into the kerosene to any required

depth. This is done by twisting a bit of wire round the scribing

point and allowing it to project downwards. The point itself serves

to give an idea of the height to which the vessel may be filled. The

liquid is adjusted till its surface is in contact with the end of the

scribing point, and the wire then projects into the liquid and forms

an electrode of constant area of surface. The scribing block is put

to earth. A charge is given to the electroscope, and the time

required for a given degree of collapse of the leaves noted.

The kerosene is then removed and its place taken by vaseline or

paraffin, known to insulate well as a standard for comparison. The

experiment is then repeated, and the time noted for the same degree of

collapse. This test, though of course rough, is generally quite

sufficient for workshop purposes, and is easily applied. Moreover, it

does not require correction for electrometer leakage, as generally

happens when more elaborate appliances are used.

The actual resistance of insulating oils depends so much on the

electrical intensity, on the duration of that intensity, and on the

previous history of the oil as to the direction of the voltage to

which it has been subjected--to say nothing of the effects of traces

of moisture--that quantitative experiments are of no value unless

they are extremely elaborate. I shall therefore only append the

following numbers due to Bouty, Ann. de Chemie et de Physique (6),

vol. xxvii. p. 62, 1892, in which the effect of the conductivity on

the determination of the specific inductive capacity was properly

allowed for:-

Carbon

Bisulphide.

Turpentine.

Benzene (C6H6) at 20° C.

Benzene at

60° C.

Specific inductive capacity

2.715

2.314

2.21

2.22

Specific resistance in ohms per cubic centimetre

1.5 x 1013,

1.75 x 1012

1.56 x 1011

7.9 x 1011

[Footnote: Professor J. J. Thomson, and Newall (Phil. Proc. 1886)

consider that carbon bisulphide showed traces of a "residual charge"

effect; hence, until this point is cleared up, we must regard Bouty's

value as corresponding only to a very short, but not indefinitely

short, period of charge. On this point the paper must be consulted.

March 1897--The writer has investigated this point by an independent

method, but found no traces of "residual charge."]

Information as to the specific inductive capacity of a large number of

oils may be found in a paper by Hopkinson, Phil. Proc. 1887, and in a

paper by Quincke in Wiedemann's Annalen, 1883.

§ 114. Imperfect Conductors.

Under this heading may be grouped such things as wood, slate, marble,

etc--in fact, materials generally used for switchboard insulation.

An examination of the insulating power of these substances has

recently been made by B. O. Peirce (Electrical Review, 11th January

1895) with quite sufficient accuracy, having in view the impossibility

of being certain beforehand as to the character of any particular

sample. The tests were made by means of holes drilled in slabs of the

material to be examined. These holes were three-eighths of an inch in

diameter, and from five-eighths to three-quarters of an inch deep, and

one inch apart, centre to centre. A voltage of about 15 volts was

employed. The following general results were arrived at:-

(1) Heating in a paraffin bath always increases the resistance of

wood, though only slightly if the wood be hard and dense.

(2) Frequent exhaustion and readmission of air above the surface of

the paraffin always has a good effect in increasing the resistance of

wood.

(3) When wood is once dry, impregnating it with paraffin tends to keep

it dry.

(4) Red vulcanised fibre, like wood, absorbs paraffin, but it cannot

be entirely waterproofed in this way.

(5) The resistance of wood with stream lines along the grain is twenty

to fifty per cent lower than when the stream lines cross the grain.

(6) The "contact" resistance between slabs of wood pressed together is

always very high.

The following table will sufficiently illustrate the results obtained.

The stone was dried in the sun for three weeks in the summer (United

States), and the wood is described as having been well seasoned:-

CURRENT WITH THE GRAIN

Lowest Resistance Highest Resistance Lowest Specific Highest Specific

between two Cups between two Cups Resistance in Resistance in

in Megohms. in Megohms. Megohms. Megohms.

Ash.

550 920 380 700

Cherry

1100 4000 2800 6000

Mahogany

430 730 310 610

Oak

220 420 1050 2200

Pine.

330 630 360 1470

Hard pine.

10 48 17 1050

Black walnut

1100 3000 320 2100

Red fibre

2 4 3 60

Slate

184 280

Soapstone.

330 500

White marble

2000 8800

§ 115. As to working the materials very little need be said.

Fibre is worked like wood, but has the disadvantage of rapidly taking

the edge off the tools. In turning it, therefore, brass-turning

tools, though leaving not quite such a perfect finish as wood-turning

tools, last much longer, and really do well enough. Fibre will not

bear heating much above 100°C--at all events in paraffin. At 140°

C. it becomes perfectly brittle. Its chief merit lies in its great

strength. So far as insulation is concerned, Mr. Peirce's experiments

show that it is far below most kinds of wood.

Slate. This is a vastly more useful substance than it is generally

credited with being. It is very easily worked at a slow speed, either

on the shaping machine or on the lathe, with tools adjusted for

cutting brass, and it keeps its figure, which is more than can be said

for most materials. It forms a splendid base for instruments,

especially when ground with a little emery by iron or glass grinders,

fined with its own dust, and French polished in the ordinary way.

Spools for coils of considerable radial dimension may be most

conveniently made of slate instead of wood or brass, both because it

keeps its shape, and because it insulates sufficiently well to stop

eddy currents--at all events, sufficiently for ordinary practice. An

appreciable advantage is that slate may be purchased at a reasonable

rate in large slabs of any desired thickness. It is generally cut in

the laboratory by means of an old cross-cut saw, but it does not do

much damage to a hard hack saw such as is used for iron or brass.

Marble. According to Holtzapffell, marble may be easily turned by

means of simple pointed tools of good steel tempered to a straw

colour. The cutting point is ground on both edges like a wood-turning

tool, and held up to the work "at an angle of twenty or thirty

degrees" (?with the horizontal). The marble is cut wet to save the

tool. As soon as the point gets, by grinding, to be about one-eighth

of an inch broad it must either be drawn down or reground; a flat

tool will not turn marble at all.

A convenient saw for marble is easily made on the principle of the

frame saw. A bit of hoop iron forms a convenient blade, and is

sharpened by being hammered into notches along one edge, using the

sharp end of a hammer head. The saw is liberally supplied with sand

and water--or emery and water, where economy of time is an object.

The sawing of marble is thus really a grinding process, but it goes on

rapidly. Marble is ground very easily with sand and water; it is

fined with emery and polished with putty powder, which, I understand,

is best used with water on cloth or felt. As grinding processes have

already been fully described, there is no need to go into them here.

I have no personal knowledge of polishing marble.

§ 116. Conductors.

The properties of conductors, more particularly of metals, have been

so frequently examined, that the literature of the subject is

appallingly heavy. In what follows I have endeavoured to keep clear

of what might properly appear in a treatise on electricity on the one

hand, and in a wiring table on the other. The most important work on

the subject of the experimental resistance properties of metals has

been done by Matthieson, Phil. Trans. 1860 and 1862, and British

Association Reports (1864); Callender, Phil. Trans. vol. clxxiii;

Callender and Griffiths, Phil. Trans. vol. clxxxii; The Committee

of the British Association on Electrical Standards from 1862 to

Present Time; Dewar and Fleming, Phil. Mag. vol. xxxvi. (1893);

Klemencic, Wiener Sitzungsberichte (Denkschrift), 1888, vol. xcvii. p.

838; Feussner and St. Lindeck, Zeitsch. fuer Inst. 'Kunde, ix. 1889,

p. 233, and B. A. Reports, 1892, p. 139. Of these, Matthieson, and

Dewar and Fleming treat of resistance generally, the latter

particularly at low temperatures.

[Footnote: The following is a list of Dr. Matthieson's chief papers on

the subject of the electrical resistance of metals and alloys: Phil.

Mag. xvi. 1858, pp. 219-223; Phil. Trans. 1858, pp. 383-388 Phil.

Trans. 1860, pp. 161-176; Phil. Trans. 1862, pp. 1-27 Phil. Mag. xxi.

(1861), pp. 107-115; Phil. Mag. xxiii. (1862), pp. 171-179;

Electrician, iv. 1863, pp. 285-296; British Association Reports,

1863, p. 351.]

Matthieson, and Matthieson and Hockin, Klemencic, Feussner, and St.

Lindeck deal with the choice of metals for resistance standards.

Callender's, and Callender and Griffiths' work is devoted to the study

of platinum for thermometric purposes.

The bibliography referring to special points will be given later. The

simplest way of exhibiting the relative resistances of metals is by

means of a diagram published by Dewar and Fleming (loc. cit.), which

is reproduced on a suitable scale on the opposite page. For very

accurate work, in which corrections for the volumes occupied by the

metals at different temperatures are of importance, the reader is

referred to the discussion in the original paper, which will be found

most pleasant reading. From this diagram both the specific resistance

and the temperature coefficient may be deduced with sufficient

accuracy for workshop purposes. In interpreting the diagram the

following notes will be of assistance. The diagram is drawn to a

scale of so-called "platinum temperatures"--that is to say, let R0,

R100, Rt be the resistances of pure platinum at 0°, 100°, and t° C.

respectively, then the platinum temperature pt is defined as

pt = 100 X (Rt-R0)/(R100-R0)

This amounts to making the temperature scale such that the temperature

at any point is proportional to the resistance of platinum at that

point. Consequently on a resistance temperature diagram the straight

line showing the relation between platinum resistance and platinum

temperature will "run out" at the platinum absolute zero, which

coincides more or less with the thermodynamic absolute zero, and also

with the "perfect gas" absolute zero. Platinum temperatures may be

taken for workshop purposes over ordinary ranges as almost coinciding

with air thermometer temperatures. The metals used by Professors

Dewar and Fleming were, with some exceptions, not absolutely pure, but

in general represent the best that can be got by the most refined

process of practical metallurgy. We may note further that the

specific resistance is only correct for a temperature of about 15° C,

since no correction for the expansion or contraction of material has

been applied.

The following notes on alloys suitable for resistance coils will

probably be found sufficient.

§ 117. Platinoid.

This substance, discovered by Martino and described by Bottomley

(Phil. Proc. Roy. Soc. 1885), is an alloy of nickel, zinc, copper, and

1 per cent to 2 per cent of tungsten, but I have not been able to

obtain an analysis of its exact composition. It appears to be

difficult to get the tungsten to alloy, and it has to be added to part

of the copper as phosphide of tungsten, in considerably greater

quantity than is finally required. The nickel is added to part of the

copper and the phosphide of tungsten, then the zinc, and then the rest

of the copper. The alloy requires to be remelted several times, and a

good deal of tungsten is lost by oxidation.

The alloy is of a fine white colour, and is very little affected by

air--in fact, it is to some extent untarnishable. The specific

resistance will be seen to be about one and a half times greater than

that of German silver, and the temperature coefficient is about 0.021

per cent per degree C. (i.e. about nineteen times less than copper,

and half that of German silver). To all intents and purposes it may

be regarded as German silver with 1 per cent to 2 per cent of

tungsten. It does not appear to have been particularly examined for

secular changes of resistance.

118. German Silver. This material has been exhaustively examined of

late years by Klemencic and by Feussner and St. Lindeck. Everybody

agrees that German silver, as ordinarily used for resistances, and

composed of copper four parts, zinc two parts, nickel one part, is

very ill-fitted for the purpose of making resistance standards. This

is due

(1) to its experiencing a considerable increase in resistance on

winding. Feussner and St. Lindeck found an increase of 1 per cent

when German silver was wound on a core of ten wire diameters.

(2) To the fact that the change goes on, though with gradually

decreasing rate, for months or years;

(3) to the fact that the resistance is permanently changed (increased)

by heating to 40° C. or over. By "artificially ageing" coils of

German silver by heating to 150° C, say for five or six hours, its

permanency is greatly improved, and it becomes fit for ordinary

resistance coils where changes of, say, 1/5000 do not matter.

It is a remarkable property of all nickel alloys containing zinc that

their specific resistance is permanently increased by heating, whereas

alloys which do not contain zinc suffer a change in the opposite

direction. The manufacturers of German silver appear to take very

little care as to the uniformity of the product put on the market;

some so-called German silver is distinctly yellow, while other samples

are bright and white.

It is noted by Price (Measurements of Electrical Resistance, p. 24)

that German silver wire is apt to exhibit great differences of

resistance within quite short lengths. This has been my own

experience as well, and is a great drawback to the use of German

silver in the laboratory, for it makes it useless to measure off

definite lengths of wire with a view to obtaining an approximate

resistance. In England German silver coils are generally soaked in

melted hard paraffin. In Germany, at all events at the Charlottenburg

Institute, according to St. Lindeck--coils are shellac-varnished and

baked. In any case it appears to be essential to thoroughly protect

the metal against atmospheric influence.

§ 119. Platinum Silver.

In the opinion of Matthieson and of Klemencic the 10 per cent silver,

90 per cent platinum alloy is the one most suitable for resistance

standards. At all events, it has stood the test of time, for, with

the following exceptions, all the British Association coils

constructed of it from 1867 to the present day have continued to agree

well together. The exceptions were three one-ohm coils, which

permanently increased between 1888 and 1890, probably through some

straining when immersed in ice. One coil changed by 0.0006 in 1

between the years 1867 and 1891. According to Klemencic, absolute

permanency is not to be expected even from this alloy.

Its recommendation as a standard depends on its chemical inertness,

its small temperature coefficient (0.00027 per degree), and its small

thermo-voltage against copper, as the following table (taken from

Klemencic) will show:-

Thermo-voltages in Micro-volts per degree against Copper

over the Range 0° to 17° C.

Platinum iridium 7.14 micro-volts per degree C.

Platinum silver 6.62 micro-volts per degree C.

Nickelin 28.5 micro-volts per degree C.

German silver 10.43 micro-volts per degree C.

Manganin (St. Lindeck) 1.5 micro-volts per degree C.

Mechanically, the platinum silver is weak, and is greatly affected as

to its resistance by mechanical strains--in fact, Klemencic considers

it the worst substance he examined from this point of view--a

conclusion rather borne out by Mr. Glazebrook's experience with the

British Association standards already referred to (B. A. Reports, 1891

and 1892).

Taking everything into account, it will probably be well to construct

standards either with oil insulation only, or to bake the coils in

shellac before testing, instead of soaking in paraffin. Fig. 89

illustrates a form of an oil immersed standard which is in use in my

laboratory, and through which a considerable current may be passed.

The oil is stirred by means of a screw propeller.

Fig. 89.

Fig. 89 represents a standard resistance for making Clerk cell

comparisons by the silver voltameter method. The framework on which

the coils are wound consists of a base and top of slate. The pillars

are of flint glass tube surrounding brass bolts, and cemented to the

latter by raw shellac. Grooves are cut in the glass sleeves to hold

the wires well apart. These grooves were cut by means of a file

working with kerosene lubrication. A screw stirrer is provided, and

the whole apparatus is immersed in kerosene in the glass box of a

storage cell. The apparatus is aged to begin with by heating to a

temperature a good deal higher than any temperature it is expected to

reach in actual work. After this the rigidity of the frame is

intended to prevent any further straining of the wire. The apparatus

as figured is not intended to be cooled to 0° C, so that it is put in

as large a box as possible to gain the advantage of having a large

volume of liquid. The top and bottom slates measure seven inches by

seven inches, and the distance between them is seven inches. The

inner coil is wound on first, and the loop which constitutes the end

of the winding is brought up to a suitable position for adjustment.

The insulation of the heavy copper connectors is by means of ebonite.

§ 120. Platinum Iridium.

Platinum 90 per cent, iridium 10 per cent. This material was prepared

in some quantity at the cost of the French Government, and distributed

for test about 1886. Klemencic got some of it as representing

Austria, and found it behaved very like the platinum silver alloy just

discussed. The temperature coefficient is, however, higher than for

platinum silver (0.00126 as against 0.00027). The mechanical

properties of the alloy are, however, much better than those of the

silver alloy; and in view of the experience with B. A. standards

above quoted, it remains an open question whether, on the whole, it

would not be the better material for standards, in spite of its

higher price. Improvements in absolute measurements of resistance,

however, may render primary standards superfluous.

§ 121. Manganin.

Discovered by Weston--at all events as to its application to

resistance coils. A glance at the diagram will exhibit its unique

properties, on account of which it has been adopted by the

Physikalisch Technischen Reichsanstalt for resistance standards. The

composition of the alloy is copper 84 per cent, manganese 12 per cent,

nickel 4 per cent, and it is described as of a steel-gray colour.

Unfortunately it is apt to oxidise in the air, or rather the manganese

it contains does so, so that it wants a very perfect protection

against the atmosphere.

Like German silver, manganin changes in resistance on winding, and

coils made of it require to be artificially aged by heating to 150°

for five hours before final adjustment. The annealing cannot be

carried out in air, owing to the tendency to oxidation. The method

adopted by St. Lindeck (at all events up to 1892) is to treat the

coil with thick alcoholic shellac varnish till the insulation is

thoroughly saturated, and then to bake the coil as described. The

baking not only anneals the wire, but reduces the shellac to a hard

and highly insulating mass.

Whether stresses of sufficient magnitude to produce serious mechanical

effects can be set up by unequal expansion of wire and shellac during

heating and cooling is not yet known, but so far as tested (and it

must be presumed that the Reichsanstalt tests are thorough) no

difficulty seems to have been met with. In course of time, however,

probably the best shellac coating will crack, and then adieu to the

permanency of the coil! This might, of course, be obviated by keeping

the coil in kerosene, which has no action on shellac, but which

decomposes somewhat itself.

The method of treatment above described suffices to render coils of

manganin constant for at least a year (in 1892 the tests had only been

made for this time) within a few thousands per cent. Manganin can be

obtained in sheets, and from this material standards of 10-2, 10-3,

and 10-4 ohms are made by soldering strips between stout copper bars,

and these are adjusted by gradually increasing their resistance by

boring small holes through them. The solder employed is said to be

"silver."

Mr. Griffiths (Phil. Trans. vol. clxxxiv. [1893], A, p. 390) has

had some experience with manganin carrying comparatively heavy

currents, under which circumstances its resistance when immersed in

water was found to rise in spite of the varnish which coated it.

Other experiments in which the manganin wire was immersed in paraffin

oil did not exhibit this effect, though stronger currents were passed.

On the whole, manganin appears to be the best material for coil boxes

and "secondary" resistance standards. Whether it is fit to rank with

the platinum alloys as regards permanency must be treated as an open

question.

§ 122. Other Alloys.

The following tables, taken from the work of Feussner and St.

Lindeck, Zeitschrift fuer Instrumenten Kunde, 1889, vol. ix. p.

233, together with the following notes, will suffice.

§ 123. Nickelin.

This is only German silver with a little less zinc, a little more

nickel, and traces of cobalt and manganese. It behaves like German

silver, but is an improvement on the latter in that all the faults of

German silver appear upon a reduced scale in nickelin.

§ 124. Patent Nickel.

Practically a copper nickel alloy, used to some extent by Siemens

and Halske. It stands pretty well in the same relation to nickelin as

the latter does to German silver. After annealing as for manganin it

can be made into serviceable standards which do not change more than a

few thousandths per cent. I have not come across a statement of its

thermo-voltage against copper.

§ 125. Constantin.

Another nickel copper alloy containing 50 per cent of each

constituent. It appears to be a serviceable substance, having a

temperature coefficient of 0.003 per cent per degree only, but an

exceedingly high thermo-voltage, viz. 40 micro-volts per degree

against copper.

1 2 3 4 5 6 7 8

German Nickelin made Rheo- Patent Nickel Manga- Nickel

Silver by Obermaier tane nese Manga-

Dia- Dia- Dia- Dia- Copper nese

meter meter meter meter Copper

1.0mm 0.1mm 0.6mm 1.0mm

Copper 60.16 61.63 54.57 53.28 74.41 74.71 70 73

Zinc 25.37 19.67 20.44 16.89 0.23 0.52 ... ...

Tin ... ... ... ... trace ... ...

Nickel 14.03 18.46 24.48 25.31 25.10 24.14 ... 3

Iron 0.30 0.24 0.64 4.46 0.42 0.70 ... ...

Cobalt trace 0.19 ... ... trace trace ... ...

Mang- trace 0.18 0.27 0.37 0.13 0.17 30 24

anese.

99.86 100.37 100.40 100.31 100.24 100.24 ... ...

Specific

resistance

30.0 33.2 44.8 52.5 34.2 32.8 100.6 47.7

Temperature

coefficient

0.00036 0.00030 0.00033 0.00041 0.00019 0.00021 0.00004 0.00003

The specific resistance is in microhms, i.e. 10-6 ohms per cubic

centimetre, and the temperature coefficient in degrees centigrade.

126. Nickel Manganese Copper.

I can find no other reference with regard to this alloy mentioned by

Lindeck. Nicholls, however (Silliman's Journal [3], 39, 171, 1890),

gives some particulars of alloys of copper and ferromanganese. The

following table is taken from Wiedemann's Beiblatter (abstract of

Nicholl's paper, 1890, p. 811). All these alloys appear to require

annealing at a red heat before their resistances are anything like

constant.

Let x be percentage of copper, then 100--x is percentage of

"ferromanganese."

Values of x. 100 99.26 91 .88 86.98 80.4 70.65

Specific

resistance

with respect

to copper

(? pure) 1 1.19 11.28 20.4 27.5 45.1

Temperature

coefficient

per degree

x 10^6(hard) 3202 2167 138 16 22 -24

Ditto (soft) ... ... 184 80 66 21

If nickel is added, alloys of much the same character are obtained,

some with negative temperature coefficients--for instance, one

containing 52.51 per cent copper, 31.27 per cent ferromanganese, and

16.22 nickel.

A detailed account of several alloys will be found in a paper by

Griffiths (Phil. Trans. 1894, p. 390), but as the constants were

determined to a higher order of accuracy than the composition of the

material--or, at all events, to a higher degree of accuracy than

that to which the materials can be reproduced--there is no advantage

in quoting them here.

CHAPTER IV

ELECTROPLATING AND ALLIED ARTS

§ 127. Electroplating.

This is an art which is usually deemed worthy of a treatise to itself,

but for ordinary laboratory purposes it is a very simple matter--so

simple, indeed, that the multiplicity of receipts as given in

treatises are rather a source of embarrassment than otherwise.

The fundamental principles of the art are:-

(1) Dirty work cannot be electroplated.

(2) Electroplated surfaces may be rougher, but will not be smoother

than the original unplated surface.

(3) The art of electroplating being in advance of the science, it is

necessary to be careful as to carrying out instructions in detail.

This particularly applies to the conditions which determine whether a

metallic deposit shall come down in a reguline or in a crystalline

manner.

§ 128. The Dipping Bath.

An acid dipping bath is one of the most useful adjuncts to the

laboratory, not only for cleansing metals for electroplating, but for

cleaning up apparatus made out of bits of brass tube and sheet, and

particularly for quickly cleaning binding screws, etc, where it is

necessary to ensure good electrical contact.

The cheapest and most satisfactory way in the end is to make up two or

three rather large baths to begin with. The glass boxes of storage

batteries do very nicely for the purpose, and being generally ground

pretty flat at the top, they may be covered by sheets of patent plate

glass, and thus preserved from the action of the air.

First Bath. A 30 or 40 per cent solution of commercial caustic soda.

Objects may be cleansed from grease in this bath by heating them as

hot as is consistent with individual circumstances, and plunging them

into it.

It is a considerable advantage to begin by removing grease from

articles subsequently to be dipped in an acid bath, both because it

saves time and acid, and because more uniform results are obtainable

when this is done than when it is omitted. It is a great advantage to

have the caustic soda solution hot. This is always done in factories

where nickel-plating is carried on, but it is inconvenient in the

laboratory. The articles after dipping in the alkali are swilled with

water, and may even be scrubbed with a brush, so as to remove greasy

matters that have been softened but not entirely removed.

Acid Bath. A convenient bath for laboratory purposes is made by

mixing two volumes of strong commercial nitric acid with one of strong

sulphuric acid in a cell measuring, say, 12 X 10 X 15 inches.

Copper or brass articles are dipped in this bath for a few seconds,

then rinsed with water, then dipped again for a second or two, or

until they appear equally white all over, and then withdrawn as

rapidly as possible and plunged into a large quantity of clean water.

Care must be taken to transfer the articles from the bath to the water

as quickly as possible, for if time be allowed for gas to be evolved,

the surfaces become mat instead of bright.

In order to save acid it is advisable to make up a third bath, using

those odds and ends of acids which gradually accumulate in the

laboratory. Sulphuric acid from the balance cases, for instance,

mixed with its own volume of commercial nitric acid, does very well.

The objects to be dipped receive a preliminary cleansing by a dip in

this bath, the strong bath being reserved for the final dip. Sheet

brass and drawn tube, as it comes from the makers, possesses a really

fine surface, though this is generally obscured by grease and oxide.

Work executed in these materials, cleaned in alkali, and dipped in

really strong acid, will be found to present a much better appearance

than work which has been filed, unless the latter be afterwards

elaborately polished.

On no account must paraffin be allowed to get into any of the baths.

When the final bath gets weak it must be relegated to a subordinate

position and a new bath set up. A weak acid bath leaves an ugly

mottled surface on brass work.

§ 129. A metallic surface which it is intended to electroplate must,

as has been mentioned, be scrupulously clean. If the metal is not too

valuable or delicate, cleaning by dipping is easy and effectual. The

following notes will be found to apply to special cases which often

occur.

(1) Silver Surfaces intended to be gilt. These are first washed

clean with soap and hot water, and polished with whitening. They are

then dipped for a moment in a boiling solution of potassium cyanide.

A 20 per cent solution of common commercial cyanide does well, but the

exact strength is quite immaterial. The cyanide is washed away in a

large volume of soft water, and the articles are kept under water till

they are scratch-brushed.

Mat surfaces are readily produced on standard silver by dipping in hot

strong sulphuric acid. The appearance of new silver coins, which is

familiar to everybody, is obtained by this process.

(2) Finely turned and finished Brass Work. If it is intended to

nickel-plate such work, and if it is desirable to obtain brightly

polished nickel surfaces, the work must be perfectly polished to begin

with. Full details as to polishing may be found in workshop books or

treatises on watch-making. It will suffice here to say that the brass

work is first smoothed by the application of successive grades of

emery and oil, or by very fine "dead" smooth files covered with chalk.

Polishing is carried out by means of rotten stone and oil applied on

leather.

In polishing turned work care must be taken to move the file, emery,

or rotten stone to and fro over the work with great regularity, or the

surface will end by looking scratchy and irregular. The first process

of cleaning is, of course, to remove grease, and this is accomplished

best by dipping in a bath of strong hot caustic soda solution, and

less perfectly by heating the work and dipping it in the cold caustic

soda bath.

During this process a certain amount of chemical action often occurs

leading to the brass surface exhibiting some discoloration. The best

way of remedying this is to dip the brass into a hot bath of cyanide

of potassium solution. If it is inconvenient to employ hot baths or

to heat the brass work, good results may be obtained by rubbing the

articles over with a large rough cork plentifully lubricated with a

strong solution of an alkali.

If the surfaces are very soiled or dirty, a paste of alkali and fine

slaked lime may be applied on a cork rubber, and this in my experience

has always been most effective and satisfactory in every way, except

that it is difficult to get into crevices. If the alkali stains the

work, a little cyanide of potassium may be rubbed over the surface in

a similar manner.

Brass work treated by either of these methods is to be washed in clean

water till the alkali is entirely removed, and may then be

nickel-plated without any preliminary scratch-brushing. The treatment

in hot baths of alkali and cyanide is the method generally employed in

American factories as a preliminary to the nickelling of small brass

work for sewing machines, etc.

(3) Copper either for use as the kathode in electrolysis calibration

experiments or otherwise is most conveniently prepared by dipping in

the acid bath, rinsing quickly in cold water, scratch-brushing under

cold water, and transferring at once to the plating bath. In the case

where the copper plates require to be weighed they are dipped into

very hot distilled water after scratch-brushing, and then dried at

once by means of a clean glass cloth.

(4) Aluminium (which, however, does not readily lend itself to plating

operations [Footnote: This difficulty has now been overcome. See

note, section 138.] ) is best treated by alkali rubbed on with a cork,

or by a hot alkaline carbonate where rubbing is inexpedient. The

clean aluminium is scratch-brushed under water, and at once

transferred to the plating bath.

(5) Iron for Nickel-plating. According to Dr. Gore

(Electra-metallurgy, p. 319) the best bath for cleaning iron is made

as follows: "One gallon of water and one pound of sulphuric acid are

mixed with one or two ounces of zinc (which of course dissolves); to

this is added half a pound of nitric acid." The writer has been

accustomed to clean iron by mechanical means, to deprive it of grease

by caustic alkali, and to finish it off by, means of a hard scratch

brush. This process has always worked satisfactorily.

(6) Articles soldered with soft solder containing lead and tin do not

readily lend themselves to electrolytic processes, the solder

generally becoming black and refusing to be coated with the

electro-deposit. Moreover, if soldered articles are boiled for any

length of time in caustic alkali during the preliminary cleansing,

enough tin will dissolve to form a solution of stannate of potash or

soda--strong enough to deposit tin on brass or copper. A method of

coppering soldered articles will be described later on.

§ 130. Scratch-brushing.

This process is generally indispensable, and to its omission is to be

traced most laboratory failures in electroplating. Scratch-brushes

may be bought at those interesting shops where "watchmakers' supplies"

are sold. It will be well, therefore, to purchase a selection of

scratch brushes, for they are made to suit particular kinds of work.

They are all made of brass wire, and vary both in hardness and in the

fineness of the wire. The simplest kind of scratch brush consists

merely of a bundle of wires bound up tightly by another wire, and

somewhat "frizzed" out at the ends (Fig. 90). A more useful kind is

made just like a rotating brush, and has to be mounted on a lathe

(Fig. 91).

Fig. 90. Fig. 91.

The scratch brush is generally, if not always, applied wet; the

lubricant generally recommended is stale beer, but this may be

replaced by water containing a small quantity of glue, or any other

form of gelatine in solution--a mere trace (say .1 per cent) is quite

sufficient. Very fair results may be got by using either pure or

soapy water. The rotating brushes require to be mounted on a lathe,

and may be run at the same speed as would be employed for turning

wooden objects of the same dimensions.

Since the brush has to be kept wet by allowing water or its equivalent

to drip upon it, it is usual to make a tin trough over which the brush

can revolve, and to further protect this by a tin hood to keep the

liquid from being thrown all over the room. In many works the brush

is arranged to lie partly in the liquid, and this does very well if

the hood is effective.

There is a superstition that electro-deposits stick better to

scratch-brushed surfaces than to surfaces which have not been so

treated, and consequently it is usual to scratch-brush surfaces before

electro-deposit. However this may be, there is no doubt that

adherence and solidity are promoted by frequent scratch-brushing

during the process of depositing metal, especially when the latter

tends to come down in a spongy manner.

Gilt surfaces--if the gilding is at all heavy--are generally dull

yellow, or even brown, when they come from the bath, and require the

scratch brush to cause the gold to brighten, an office which it

performs in a quite striking manner. The same remark applies to

silvered surfaces, which generally leave the bath a dead white--at

all events if the deposit is thick, and if ordinary solutions are

employed. In either case the touch of the scratch brush is magical.

§ 131. Burnishing.

Burnishers of steel, agate, or bloodstone can be bought at the shops

where scratch brushes are sold, and are used to produce the same

brightening effect as can be got by scratch-brushing. The same

solutions are employed, but rather stronger, and the burnisher is

swept over the surface so as to compress the deposited metal.

Burnishing is rather an art, but when well done gives a harder and

more brilliant (because smoother) surface than the scratch brush. On

the whole, steel burnishers are the most convenient if in constant

use.

If the burnishing tools have to lie about, steel is apt to rust,

unless carefully protected by being plunged in quicklime or thickly

smeared with vaseline, and the least speck of rust is fatal to a

burnisher. In any case the steel requires to be occasionally

repolished by rouge and water on a bit of cloth or felt. The process

of burnishing is necessarily somewhat slow and tedious, and as a rule

is not worth troubling about except in cases where great permanence is

required.

The burnisher is moved over the work somewhat like a pencil with

considerable pressure, and care is taken to make the strokes as

uniform in direction as possible; otherwise the surface looks

non-uniform, and has to be further polished by tripoli, whitening,

etc, before it is presentable.

§ 132. Silver-plating.

The most convenient solution for general purposes is an 8 to 10 per

cent solution of the double cyanide of silver and potassium together

with 1 or 2 per cent of "free" potassium cyanide. Great latitude is

permissible in the strength of solution and density of current. As

commercial cyanide of potassium generally contains an unknown

percentage of other salts, which, however, do not interfere with its

value for the purpose of silver-plating, the simplest procedure is as

follows.

For every 100 c.c. of plating solution about 7 grms. of dry

crystallised silver nitrate are required. The equivalent amount of

potassium cyanide (if dry and pure) is 5.2 grms, but commercial

cyanide may contain from 50 per cent upwards to 96 per cent in the

best fused cyanide made from ferrocyanide only. An approximate idea

of the cyanide content can be obtained from the dealers when the salt

is purchased, and this is all that is required.

A quantity slightly in excess of the computed amount of cyanide is

dissolved in distilled water, and this is cautiously added to the

solution of the silver nitrate till precipitation is just complete.

The supernatant liquors are then drained away, and the precipitate

dissolved by adding a sufficiency of the remaining cyanide; this

process is assisted by warming and stirring.

An allowance of about one-tenth of the whole cyanide employed may be

added to form "free" cyanide, and the solution made up to the strength

named. It is advisable to begin with the cyanide in a moderately

strong solution, for the sake of ease in dissolving the precipitate.

This solution will deposit silver upon articles of copper or brass

immersed in it even without the battery, but the coat will be thin.

The solution is used cold, with a current density of about 10 to 20

ampères per square foot. The articles to be silvered are

scratch-brushed, washed, and electroplated, till they begin to look

undesirably rough. They are then taken out of the bath, rebrushed,

and the process continued till a sufficiency of silver is deposited.

Four grammes weight of silver (nearly) is deposited per ampère hour.

It is best to use a fine silver anode, so that the solution, does not

get contaminated by copper.

In most factories it is usual to "quicken" the objects to be silvered

before placing them in the electrolysis vats, because the deposit is

said to adhere better in consequence of this treatment. I have never

found it any improvement for laboratory purposes, but it is easy to

do. A dilute (say 2 per cent) solution of cyanide of mercury is

required containing a little free cyanide. The objects to be

"quickened" are scratch-brushed and dipped into the cyanide of mercury

solution till they are uniformly white; it is generally agreed that

the less the mercury deposited the better, so long as a perfect

coating is obtained. The objects are rinsed after quickening, and put

in the depositing bath at once.

The mat surface of silver obtained by electrolysis of the cyanide is

very beautiful--one of the most beautiful things in nature--shining

with incomparable crystalline whiteness. So delicate is it, however,

for so great is the surface it exposes, that it is generally rapidly

deteriorated by exposure to the air. It may be protected to some

extent by lacquering with pale lacquer, but it loses some of its

brilliancy and purity in the process. The deposit is generally

scratch-brushed or burnished down to a regular reflecting surface.

§ 133. Cold Silvering.

A thin but brilliant coat of silver may be readily applied to small

articles of brass or copper in the following way. A saturated

solution of sodium sulphite (neutral) is prepared, and into this a 10

per cent solution of nitrate of silver is poured so long as the

precipitate formed is redissolved. A good deal of silver may be got

into solution in this way. Articles to be silvered need only to be

cleaned, brushed, and dipped in this solution till a coat of the

required thickness is obtained.

I must admit, however, that the coating thus laid on does not appear

to be so permanent as one deposited by simple immersion from the

cyanide solution, even though it is thicker. The cyanide plating

solution will itself give a good coat of silver if it is used boiling,

and if a little potassium cyanide be added.

For purposes of instrument construction, however, a thin coat of

silver is seldom to be recommended, on account of its liability to

tarnish and its rapid destruction when any attempt is made to repolish

it. For these reasons, nickel or gold plating is much to be

preferred.

§ 134. Gilding.

This art deserves to be much more widely practised than is usual in

laboratories. Regarded as a means of preserving brass, copper, or

steel, it is not appreciably more "time robbing" than lacquering, and

gives infinitely better results. Moreover, it is not much more

expensive. Strange as it may seem, the costliness of gilding seldom

lies in the value of the gold deposited; the chief cost is in the

chemicals employed to clean the work, and in interest on the not

inconsiderable outlay on the solution and anode.

The easiest metal to gild is silver, and it is not unusual to give

base metals a thin coating of silver or copper, or both, one after the

other, before gilding, in order to secure uniformity. To illustrate

the virtue of a thin layer of gold, I will mention the following

experiment. About three years ago I learned for the first time that

to "clean" the silver used in a small household required at least an

hour's labour per diem. I further ascertained that most of this time

is spent on the polishing part of the process.

As this seemed a waste of labour, I decided to try the effect of

gilding. In order to give the proposal a fair trial I gilt the

following articles: half a dozen table spoons and forks, a dozen

dessert forks and spoons, and a dozen tea spoons. These were all

common electroplated ware. They were weighed before and after

gilding, and it was with difficulty that the increase of weight was

detected, even though a fine bullion balance was employed. On

calculating back to money, it appeared that the value of the gold

deposited was about threepence. Assuming that an equal weight of

silver had been accidentally dissolved by the free cyanide during the

plating--which is unlikely--the total amount of gold deposited would

be worth, say, sixpence.

After three years' continuous use the gilding is still perfect, except

at the points on which the spoons and forks rest, where it is

certainly rather shabby. Meanwhile the "gold" plate only requires to

be washed with hot water and soap to keep it in perfect order, a much

more cleanly and expeditious process than that of silver cleaning.

§ 135. Preparing Surfaces for Gilding.

Ordinary brass work--rough or smooth--may for purposes of

preservation be dipped, scratch-brushed, and gilt at once. Seven

years ago the writer gilt the inside of the head of a copper water

still, and simply scratch-brushed it; it is to-day in as good order as

when it was first done. If it is intended to gild work from the

first, with the view of making an exceptionally fine job of it,

"gilding metal," i.e. brass containing one to one and a quarter

ounces of zinc to the pound of copper may be specified. From its

costliness, however, this is only desirable for small work.

Iron and steel are generally given a preliminary coating of copper,

but this may be dispensed with though with no advantage--by using a

particular process of gilding.

Base metals, zinc, pewter, lead, etc, are first coppered in a cyanide

of copper solution, as will be described under the head of

Copper-plating. If it is intended to gild soldered articles,

the preliminary coating of copper is essential.

The most convenient vessel for holding a gilding solution is

undoubtedly one formed of enamelled iron. Particularly useful are the

buckets and "billies" (i.e. cylindrical cans) made of this material.

These vessels may be heated without any fear of a smash, and do not

appear to be appreciably affected by gilding solutions--at all events

during several days or weeks. The avoidance of all risk of breakage

when twenty or thirty pounds' worth of solution is in question is a

matter of importance.

Under no circumstances is it desirable to use anything but the purest

gold and best fused cyanide (called "gold" cyanide) in the preparation

of the solutions. The appearance of a pure gold deposit is far richer

than of one containing silver, and its resistance to the atmosphere is

perfect; moreover, in chemico-physical processes one has the

satisfaction of knowing what one is dealing with.

§ 136. Gilding Solutions.

The strength of solution necessary for gilding brass, copper, and

silver is not very material. About one to two pounds of "gold"

potassium cyanide (? 96 per cent KCN) per gallon does very well. The

gold is best introduced by electrolysing from a large to a small gold

electrode. One purchases a plate of pure gold either from the mint or

from reliable metallurgists (say Messrs. Johnson and Matthey of

London), and from this electrodes are cut.

The relative areas of the electrodes do not really much matter. I

have used an anode of four times the area of the cathode. The

solution is preferably heated to a temperature of about 50° C, and a

strong current is sent through it, say twenty amperes to the square

foot of anode. The electrodes must be suspended below the surface of

the solution by means of platinum wires. If the gold plates are only

partly immersed, they dissolve much more rapidly where they cut the

surface, possibly on account of the effect of convection currents,

though so far as the writer is aware no proper explanation has yet

been given.

After a time gold begins to be deposited on the cathode in a powdery

form, for which reason it is a good plan to begin by wrapping the

latter in filter paper. The process has gone on for a sufficient time

when a clean bit of platinum foil immersed in the place of the cathode

becomes properly gilt at a current density of about ten amperes per

square foot.

The powdery gold deposited on the cathode while preparing the solution

can be scraped off and melted for further use, or the whole cathode

may now be used as an anode. The platinum foil testing cathode may

also be "stripped" by making it an anode, and is for this reason

preferable to German silver or copper, which would contaminate the

solution while the "stripping" process was in progress.

For general purposes a current density of say ten to fifteen amperes

per square foot may be used, but this may be considerably varied, so

long as the upper limit is not greatly overpassed. During

gold-plating there is a considerable advantage in keeping the

electrodes moving or the solution stirred.

After immersing the cleaned and scratch-brushed articles, depositing

may go on for about three minutes, after which they are removed from

the bath and examined, in order to detect any want of uniformity in

the deposit.

The articles should be entirely immersed; if this is not done,

irregularity is apt to appear at the surface. Platinum wires employed

as suspenders, and coated along with the articles to be gilt, may also

be cleaned without loss by making them anodes. If, on examination,

all is found to be going on well, reimmerse the cathodes, and continue

plating till they appear of a dull yellowish brown (this will occur in

about four minutes), then remove them, rinse and scratch-brush them,

and replace them in the bath.

When a second coat appears to be getting rather brown than yellowish

brown, i.e. of the colour of wet wash-leather, the removal, followed

by scratch-brushing, may be repeated, and for nearly all laboratory

purposes, the articles are now fully gilt.

The coating of gold deposited from a hot cyanide solution is spongy in

the extreme, and if the maximum wear-resisting effect is to be

obtained, it is advisable to burnish the gold rather than to rely upon

the scratch brush alone.

If the area of the cathode exceeds that of the anode the solution is

said to grow weaker, and vice versa. This may be remedied in the

former case by an obvious readjustment; the latter introduces no

difficulty so far as I know except when plating iron or steel.

The student need not be troubled at the poor appearance of the deposit

before it is scratch-brushed. Heavy gold deposits are almost always

dull, not to say dirty, in appearance till the burnisher or scratch

brush is applied. On the other hand, the deposit ought not to get

anything like black in colour.

The following indications of defects may be noted--they are taken from

Gore. I have never been really troubled with them.

The deposit is blackish. This is caused by too strong a current in

too weak a bath. This may be remedied to some extent by stirring or

keeping the cathode in motion. The obvious remedy is to add a little

cyanide of gold.

The gold anode gets incrusted. This is a sign that the bath is

deficient in potassium cyanide. The gold anode gets black and gives

off gas. The solution is deficient in cyanide, and too large a

current is being passed.

If a bright surface is desired direct from the bath, some caustic

potash (say 2 per cent) may, according to Gore, be added, or the

articles may be plated only slightly by using a weak current and

taking them out directly they show signs of getting dull. By a weak

current I mean one of about five amperes per square foot.

The deposit is said to be denser if the solution be heated as

directed; but the bath will gild, though not quite so freely when

cold.

To gild iron or steel directly, dilute the bath as above recommended

some five or six times, add about 1 per cent of potassium cyanide, and

gild with a very weak current (say two or three amperes per square

foot) in the cold. Frequent scratch-brushing will be found requisite

to secure proper adherence.

It is generally recommended to gild brass or German silver in

solutions which are rather weak, but in the small practice which

occurs in the laboratory a solution prepared as suggested does

perfectly for everything except iron or steel. The scratch-brushing

should be done over a large photographic developing dish to avoid loss

of gold. It is a good plan to rinse the articles after leaving the

bath in a limited quantity of distilled water, which is afterwards

placed in a "residue" bottle, and then to scratch-brush them by hand

over the dish to catch fine gold. When any loose dust is removed the

articles may be scratched in the lathe without appreciable further

loss.

Silver-gilt articles tend to get discoloured by use, but this

discoloration can be removed by soap and water. After long use a gold

cyanide bath tends to alter greatly in composition, In general, the

bath tends to grow weaker, from the fact that there is a strong

temptation to gild as many articles at once as possible.

It is therefore a good plan to keep a rough profit and loss account of

the gold in order to find the quantity in solution. Fifty dwts. per

gallon (or 78 grms. per 4.5 litres) is recommended. A gallon of

solution of this strength is worth about eleven pounds sterling in

gold and cyanide, and a serviceable anode will be worth about 10

pounds. (Fine gold is worth nominally four pounds four shillings and

eleven pence ha'penny per oz.) Gold may be easily obtained containing

less impurity than one part in ten thousand.

§ 137. Plating with Copper.

Copper may be deposited from almost any of its salts in reguline form,

the sulphate and nitrate being most usually employed. In the

laboratory a nearly saturated solution of sulphate of copper with 1 or

2 per cent of sulphuric acid will answer most purposes. A current

density of, at most, fifteen amperes per square foot may be used,

either for obtaining solid deposits for constructional purposes or for

calibrating current measuring instruments by electrolysis. A copper

anode is of course employed.

When coppering with a view to obtaining thick deposits it is a good

plan to place the electrodes several inches apart, and, if possible,

to keep the liquid stirred, as there is a considerable tendency on the

part of copper deposits to grow out into mossy masses wherever the

current density exceeds the limit mentioned. As the masses grow

towards the anode the defect naturally tends to increase of itself,

hence the necessity for care. The phenomenon is particularly marked

at the edges and corners of the cathode.

If the deposit becomes markedly irregular, the best plan is to stop

the process and file the face of the deposit down to approximate

smoothness. In coppering it is of the utmost importance that the

cathode be clean and free from grease; it must never be touched (by

the finger, for instance) from the time it is scratch-brushed till it

is immersed in the plating bath. Any grease or oxidation tends to

prevent the copper deposit adhering properly.

A copper deposit oxidises very easily when exposed to the air.

Consequently if the surface be required free from oxide, as, for

instance, when it is to be silvered or gilt, it must be quickly washed

when withdrawn from the coppering bath, scratch-brushed, and

transferred immediately to the silvering or gilding bath.

If the surface is to be dried, as in electrolysis calibrations, it

must be rinsed quickly with boiling water and pressed between sheets

of filter paper. Another method which has been recommended is to

rinse the copper in--water slightly acidulated with sulphuric acid

(which prevents oxidation), then in distilled water, and to dry by

blotting paper and in front of a fire, taking care not to make the

plate too hot. The wash water is sufficiently acidulated by the

addition of two or three drops of acid per litre. So far as I know,

the method of washing in acidulated water was first proposed by Mr. T.

Gray.

§ 138. Coppering Aluminium.

A good adherent deposit of copper on aluminium used to be considered a

desideratum in the days when it afforded the only means of soldering

the latter. Many receipts have been published from time to time, and

I have tried, I think, most of them. On no occasion, however, till

this year (1896), have I succeeded in obtaining a deposit which would

not strip after it was tinned and soldered, though it is not difficult

to get apparently adherent deposits so long as they are not operated

upon by the soldering iron. The best of the many solutions which have

been proposed in years gone by is very dilute cupric nitrate with

about 5 per cent of free nitric acid.

The problem of electroplating aluminium which I have indicated as

awaiting a solution has at last found one. In the Archives des

Sciences physiques et naturelles de Genève for December 1895 (vol.

xxxiv. p. 563) there is a paper by M. Margot on the subject, which

discloses a perfectly successful method of plating aluminium with

copper. The paper itself deals in an interesting way with the theory

of the matter--however, the result is as follows.

(1) The aluminium articles are boiled for a few minutes in a strong

solution of ordinary washing soda. The aluminium surface is thus

corroded somewhat, and rendered favourable to the deposit of an

adherent film of copper. After removal from the soda solution the

aluminium is well washed and brushed in running water.

(2) The articles are dipped for thirty seconds or so in a hot 5 per

cent solution of pure hydrochloric acid.

(3) After dipping in the hydrochloric acid, the work is instantly

plunged into clean water for about one second, so as to remove nearly,

but not quite, all of the aluminium chloride.

(4) The work is transferred to a cold dilute (say 5 per cent) solution

of cupric sulphate slightly acidulated with sulphuric acid. The

degree of acidulation does not appear to be very important, but about

one-tenth per cent of strong acid does well.

If the preliminary processes have been properly carried out the

aluminium will become coated with copper, and the process is

accompanied by the disengagement of gas. It appears to be a rule that

if gas is not given off, the film of copper deposited is non-adherent.

The work must be left in the copper sulphate solution till it has

received a uniform coating of copper.

(5) When this is the case the work is removed--well washed so as to

get rid of the rest of the aluminium chloride, and then electroplated

by the battery in the ordinary copper sulphate bath.

If the operation (4) does not appear to give a uniform coat, or if gas

is not evolved from every part of the aluminium surface, I find that

operations (2) and (3) may be repeated without danger, provided that

the dip in the hydrochloric acid is shortened to two or three

seconds.

The copper layer obtained by Margot's method is perfectly

adherent--even when used as a base for ordinary solder--though in

this case it can be stripped if sufficient force is applied.

Since the solder recommended by M. Margot for aluminium contains zinc,

it does not run well when used to unite aluminium to copper, brass,

iron, etc. In this case, therefore, I have found the most

advantageous method of soldering to be by way of a preliminary

copper-plating.

The success of M. Margot's method depends in my experience on

obtaining just the proper amount of aluminium chloride in contact with

the aluminium when the latter is immersed in the copper sulphate

solution.

§ 139. The process of copper-plating from sulphate or nitrate may,

according to Mr. Swan (Journal of the Royal Institution, 1892, p.

630), be considerably accelerated by the addition of a trace of

gelatine to the solution. As success appears to depend upon hitting

the exact percentage amount of the gelatine, which must in any case be

but a fraction of one per cent, and as Mr. Swan refrains from stating

what the amount is, I am unable to give more precise instructions. A

few experiments made on the subject failed, doubtless through the

gelatine content not having been rightly adjusted. Mr. Swan claims to

be able to get a hard deposit of copper with a current density of 1000

amperes per square foot, but seems to recommend about one-tenth of

that amount for general use.

The solution employed is a mixture of nitrate of copper and ammonium

chloride--proportions not stated. Electrolytic copper, as generally

prepared, is very pure, but this is a mere accident depending on the

impurities which, as a rule, have to be got rid of. Electrolysis

seems to have no effect in purifying from arsenic, for instance.

Roughly speaking, about 11 grms. of copper are deposited per ampere

hour from cupric salt solutions. When the current density is too high

the anode suffers by oxidation, and this introduces a large and very

variable resistance into the circuit.

§ 140. Alkaline Coppering Solution

Coppering Base Metals. It is often desirable to coat lead, zinc,

pewter, iron, etc, with a firm and uniform layer of copper

preparatory to gilding or silvering. If copper or brass articles are

soldered with soft solder it is found that the solder does not become

silvered or gilt along with the rest of the material, but remains

uncoated and of an ugly dark colour. This defect is got over by

giving a preliminary coating of copper.

This is done in an alkaline solution, generally containing cyanogen

and ammonia. The following method has succeeded remarkably well with

me. The receipt was taken originally from Gore's Electro-metallurgy,

p. 208. A solution is made of 50 grms. of potassium cyanide

(ordinary commercial, say, 75 per cent) and 30 grms. of sodium

bisulphite in I.5 litres of water. Thirty-five grammes of cupric

acetate are dissolved in a litre of water, and 20 cubic centimetres of

the strongest liquid ammonia are added. The precipitate formed must

be more or less dissolved to a strong blue solution. The cyanide and

bisulphite solution is then added with warming till the blue colour is

destroyed. This usually requires the exact amount of cyanide and

bisulphite mentioned, but I have not found it essential to entirely

destroy the colour.

The solution contains cuprocyanide of sodium and ammonium (?), which

is not very soluble, and this salt tends to be deposited in granular

crystalline masses on standing. However, at a temperature of 50° C.

the above receipt gives an excellent coppering liquid, which will coat

zinc with a fine reguline deposit. Brass or copper partly smeared

with solder will receive a deposit of copper on the latter as well as

on the former, and, moreover, a deposit which appears to be perfectly

uniform.

In using the bath the anode tends, as a rule, to become incrusted, and

this rapidly increases the resistance of the cell, so that the current

falls off quickly. The articles should be scratch-brushed and plated

for about two minutes with a current density of about ten ampères per

square foot.

As soon as the deposit begins to look red the articles are to be

removed and rebrushed, after which the process may be continued.

About five minutes' plating will give a copper deposit quite thick

enough after scratch-brushing to allow of a very even gilding or

silvering.

Aluminium appears to be fairly coated, but, as usual, the copper

strips after soldering. Iron receives an excellent and adherent coat.

I do not think that the formation of a crust upon the anode can be

entirely prevented. According to Gore, its formation is due to the

solution being too poor in copper, but I have added a solution of the

acetate of copper and ammonium till the colour was bright blue without

in any way reducing the incrustation. If the solutions become

violently blue it is perhaps as well to add a little more cyanide and

bisulphite, but I have not found such an addition necessary. The

process is one of the easiest and most satisfactory in

electro-metallurgy.

§ 141. Nickel-plating.

An examination of several American samples of nickel-plated goods has

disclosed that the coating of nickel is, as a rule, exceedingly thin.

This is what one would expect from laboratory repetition of the

processes employed.

Commercial practice in the matter of the composition of nickelling

solutions appears to vary a good deal. Thin coatings of nickel may be

readily given in a solution of the double sulphate of nickel and

ammonia, which does rather better if slightly alkaline. Deposits from

this solution, however, become gray if of any thickness, and,

moreover, are-apt to flake off the work. The following solution has

given very good results with me. It is mentioned, together with

others, in the Electrical Review, 7th June 1895.

The ingredients are:-

Nickel sulphate 5 parts

Ammonia sufficient to neutralise the nickel salt.

Ammonium tartrate 3.75 parts

Tannin 0.025 parts

Water 100 parts

The nickel sulphate and ammonia are dissolved in half the water, the

ammonium tartrate in the other half with the tannin. The solutions

are mixed and filtered at about 40° C. This solution works well at

ordinary temperatures, or slightly warm, with a current density of ten

ampères per square foot. In an experiment made for the purpose I

found that plating may go on for an hour in this solution before the

deposit begins to show signs of flaking off. The deposit is of a fine

white colour.

The resistance of the bath is rather high and rather variable,

consequently it is as well to have a current indicator in circuit, and

it may well happen that five or six volts will be found requisite to

get the current up to the value stated. For nickelling small objects

of brass, such as binding screws, etc, it is very necessary to be

careful as to the state of polish and uniformity of their surfaces

before placing them in the plating bath. A polished surface will

appear when coated as a polished surface, and a mat surface as a mat

surface; moreover, any local irregularity, such as a speck of a

foreign metal, will give rise to an ugly spot in the nickelling bath.

For this reason it is often advisable to commence with a coat of

copper laid on in an alkaline solution and scratch-brushed to absolute

uniformity.

An examination of the work will, however, disclose whether such a

course is desirable or not; it is not done in American practice, at

all events for small brass objects. These are cleaned in alkali and

in boiling cyanide, which does not render a polished surface mat, as

weak acid is apt to do, and are then coated with a current density of

about ten ampères per square foot.

In spite of what is to be found in books as to the ease with which

nickel deposits may be polished, I find that the mat surface obtained

by plating on an imperfectly polished cathode of iron is by no means

easily polished either by fine emery, tripoli, or rouge.

Consequently, as in the case of brass, if a polished surface is

desired, it must be first prepared on the unplated cathode. In this

case, even if the deposit appears dull, but not gray, it may be easily

polished by tripoli and water, using a cork as the polisher.

Scratch-brushing with brass wire, however, though possibly not with

German silver wire, brightens the deposit, but discolours it. When

the deposit becomes gray I have not succeeded in polishing it

satisfactorily.

Soldered brass or iron may be satisfactorily coated with nickel by

giving it a preliminary coating of copper in the cyanide bath. On the

whole, I recommend in general that iron be first coated with copper in

the alkaline bath, scratch-brushed, and then nickel-plated, and this

whether the iron appears to be uniform or not. Much smoother,

thicker, and stronger coats of nickel are obtained upon the

copper-plated surface than on the iron one, and the coating does not

become discoloured (? by iron rust) in the same way that a coating on

bare iron does. The copper surface may be plated for at least an hour

at a density of ten ampères per square foot without scaling.

Scales or circles divided on brass may be greatly improved in

durability by nickel--plating. For this purpose the brass must be

highly polished and divided before it is nickelled.

The plating should be continued for a few minutes only, when a very

bright but thin coat of nickel will be deposited; it then only

remains to wash and dry the work, and this must be done at once. If

the nickel is deposited before the scale or circle is engraved, very

fine and legible divisions are obtained, but there is a risk that

flakes of nickel may become detached here and there in the process of

engraving.

142. Miscellaneous Notes on Electroplating.

Occasionally it is desirable to make a metallic mould or other object

of complex shape. The quickest way to do this is to carve the object

out of hard paraffin, and then copy it by electrotyping. Electrotype

moulds can be made in many ways. The easiest way perhaps is to take a

casting in plaster of Paris, or by means of pressure in warm

gutta-percha.

In cases where the mould will not draw, recourse must be had to the

devices of iron-founders, i.e. the plaster cast must be made in

suitable pieces, and these afterwards fitted together. This process

can occasionally be replaced by another in which the moulding material

is a mixture of treacle and glue. The glue is soaked in cold water

till it is completely soft. The superfluous water thrown away,

one-fourth part by volume of thick treacle is added, and the mixture

is melted on the water bath; during which process stirring has to be

resorted to, to produce a uniform mixture.

This liquid forms the moulding mixture, and it is allowed to flow

round the object to be copied, contained in a suitable box, whose

sides have been slightly oiled. The object to be copied should also

be oiled. After some hours, when the glue mixture has set, it will be

found to be highly elastic, so that it may be pulled away from the

mould, and afterwards resume very nearly its original form.

One drawback to the use of these moulds lies in the fact that the

gelatine will rarely stand the plating solution without undergoing

change, but this may be partially obviated by dipping it for a few

seconds in a 10 per cent solution of bichromate of potash, exposing it

to the sunlight for a few minutes, and then rinsing it.

In order to render the surface conducting, it is washed over with a

solution of a gold or silver salt, and the latter reduced in situ to

metal by a suitable reagent. A solution of phosphorus is the most

usual one (see Gore, Electro-metallurgy, p. 216). Such a mould may

be copper-plated in the sulphate bath, connection being made by wires

suitably thrust into the material.

Plaster of Paris moulds require to be dried and waxed by standing on a

hot plate in melted wax before they are immersed in the plating bath.

In this case the surface is best made conducting either by silvering

it by the silvering process used for mirrors, or by brushing it over

with good black lead rendered more conducting by moistening with an

ethereal solution of chloride of gold and then drying in the sun.

The brushing requires a stiff camel's-hair pencil of large size cut so

that the hairs project to a distance of about a quarter of an inch

from the holder. The brushing must continue till the surface is

bright, and is often a lengthy process.

The same process of blackleading may be employed to get a coat of

deposited metal which will strip easily from the cathode.

In all cases where extensive deposits of copper are required, the

growth takes place too rapidly at the corners. Consequently it is

often desirable to localise the action of the deposit. A "stopping"

of ordinary copal varnish seems to be the usual thing, but a thin coat

of wax or paraffin or photographic (black) varnish does practically as

well.

I do not propose to deal with the subject of electrotyping to any

extent, for if practised as an art, a good many little precautions are

required, as the student may read in Gore's Electro-metallurgy. The

above instructions will be found sufficient for the occasional use of

the process in the construction of apparatus, etc. There is no

advantage in attempting to hurry the process, a current density of

about ten ampères per square foot being quite suitable and

sufficiently low to ensure a solid deposit.

§ 143. Blacking Brass Surfaces.

A really uniform dead-black surface is difficult to produce on brass

by chemical means. A paste of nitrate of copper and nitrate of silver

heated on the brass is said to give a dead-black surface, but I have

not succeeded in making it act uniformly. For optical purposes the

best plan is to use a paint made up of "drop" black, ground very fine

with a little shellac varnish, and diluted for use with alcohol. No

more varnish than is necessary to cause the black to hold together

should be employed.

In general, if the paint be ground to the consistency of very thick

cream with ordinary shellac varnish it will be found to work well when

reduced by alcohol to a free painting consistency.

A very fine gray and black finish, with a rather metallic lustre, may

be easily given to brass work. For this purpose a dilute solution of

platinum tetrachloride (not stronger than 1 per cent) is prepared by

dissolving the salt in distilled water. The polished brass work is

cleaned by rubbing with a cork and strong potash till all grease has

disappeared, as shown by water standing uniformly on the metal and

draining away without gathering into drops.

After copious washing the work is wholly immersed in a considerable

volume of the platinum tetrachloride solution at the ordinary

temperature. After about a quarter of an hour the brass may be taken

out and washed. The surface will be found to be nicely and uniformly

coated if the above instructions have been carried out, but any

finger-marks or otherwise dirty places will cause irregularity of

deposit. If the process has been successful it will be found that the

deposit adheres perfectly, hardly any of it being removed by vigorous

rubbing with a cloth. If the deposit is allowed to thicken--either

by leaving the articles in the solution too long or heating the

solution, or having it too strong--it will merely rub off and leave

an irregular surface.

This process succeeds well with yellow brass and Muntz metal, either

cast or rolled, but it does not give quite such uniform (though still

good) results with gun-metal, on which, however, the deposit is darker

and deader in appearance.

A book might be written (several have been written) on the art of

metal colouring, but though doubtless a beautiful and delicate art, it

is of little service in the laboratory. For further information the

reader may consult a work by Hiorns.

§ 144. Sieves.

Properly graded sieves with meshes of a reliable size are often of

great use. They should be made out of proper "bolting" cloth, a

beautiful material made for flour-millers. Messrs. Henry Simon and

Company of Manchester have kindly furnished me with the following

table of materials used in flour-milling.

Sieves made of these materials will be found to work much more quickly

and satisfactorily than those made from ordinary muslin or wire gauze.

Relative Bolting Value of Silk, Wire, and Grit Gauze

Threads per inch Trade No. Trade No. Trade No. of

Approximate. of Silk. of Wire. Grit Gauze.

18 0000 18 16

22 000 20 20

28 00 26 26

38 0 32 34

48 1 40 44

52 2 45 50

56 3 50 54

60 4 56 58

64 5 60 60

72 6 64 66

80 7 70 70

84 8 80 80

94 9

106 10

114 11

124 12

130 13

139 14

148 15

156 16

163 17

167 18

170 19

173 20

§ 145. Pottery making in the Laboratory.

When large pieces of earthenware of any special design are required,

recourse must be had to a pottery. Small vessels, plates, parts of

machines, etc, can often be made in the laboratory in less time than

it would take to explain to the potter what is required. For this

purpose any good pipeclay may be employed. I have used a white

pipe-clay dug up in the laboratory garden with complete success.

The clay should be kneaded with water and squeezed through a cloth to

separate grit. It is then mixed with its own volume or thereabouts of

powdered porcelain evaporating basins, broken basins being kept for

this purpose. The smoothness of the resulting earthenware will depend

on the fineness to which the porcelain fragments have been reduced. I

have found that fragments passing a sieve of sixty threads to the inch

run, do very well, though the resulting earthenware is decidedly

rough.

The porcelain and clay being thoroughly incorporated by kneading, the

articles are moulded, it being borne in mind that they will contract

somewhat on firing. [Footnote: The contraction depends on the

temperature attained as well as on the time. An allowance of one part

in twelve will be suitable in the case considered.] The clay should

be as stiff as is convenient to work, and after moulding must be

allowed to get thoroughly dry by standing in an airy place; the

drying must not be forced, especially at first, or the clay will

crack.

Small articles are readily fired in a Fletcher's crucible furnace

supplied with a gas blow-pipe; the furnace is heated gradually to

begin with. When a dull red heat is attained, the full power of the

blast may be turned on, and the furnace kept at its maximum

temperature for three or four hours at least, though on an emergency

shorter periods may be made to do.

The articles are supported on a bed of white sand; after firing, the

crucible furnace must be allowed to cool slowly. It must be

remembered that the furnace walls will get hot externally after the

first few hours, consequently the furnace must be supported on bricks,

to protect the bench.

The pottery when cold may be dressed on a grindstone if necessary.

This amateur pottery will be found of service in making small fittings

for switch-boards, commutators, and in electrical work generally.

Pottery made as described is very hard and strong, the hardness and

strength depending in a great degree on the proportion of powdered

porcelain added to the clay, as well, of course, as on the quality of

both of these materials.

It is a good plan to knead a considerable quantity of the mixture,

which may then be placed in a well-covered jar, and kept damp by the

addition of a little water.

Pottery thus made does not require to be glazed, but, of course, a

glaze can be obtained by any of the methods described in works on

pottery manufacture. The following glaze has been recommended to me

by a very competent potter:-

Litharge

7 parts by weight

Ground flint

2 parts by weight

Cornish stone or felspar

1 parts by weight

These ingredients are to be ground up till they will pass the finest

sieve--say 180 threads to the inch. They are then mixed with water

till they form a paste of the consistency of cream. They must, of

course, be mixed together perfectly. The ware to be glazed is dipped

into the cream after the first firing; it is then dried as before and

refired. The glaze will melt at a bright red heat, but it will crack

if not fired harder; the harder it is fired the less likely is it to

crack.

If colouring matters are added they must be ground in a mill free from

iron till they are so fine that a thick blanket filter will not filter

them when suspended in water. This remark applies particularly to

oxide of cobalt.

APPENDIX

PLATINISING GLASS

IN the Philosophical Magazine for July 1888 (vol. xxvi. p. 1) there

is a paper by Professor Kundt translated from the Sitzungsberichte of

the Prussian Academy. This paper deals with the indices of refraction

of metals. Thin prisms were obtained by depositing metals

electrolytically on glass surfaces coated with platinum. The

preparation of these surfaces is troublesome. Kundt recounts that no

less than two thousand trials were made before success was attained.

A detailed account of the preparation of these surfaces is not given

by Kundt, but one is promised--a promise unfortunately unfulfilled so

far as I am able to discover. A hunt through the literature led to

the discovery of the following references: Central Zeitung fuer Optik

und Mechanik, p. 142 (1888); Dingler's Polytechnik Journal, Vol.

cxcv. p. 464; Comptes Rendus, vol. lxx. (1870).

The original communication is a paper by Jouglet in the Comptes

Rendus, of which the other references are abstracts. The account in

Dingier is a literal translation of the original paper, and the note

in the Central Zeitung is abbreviated sufficiently to be of no value.

The details are briefly as follows:-

One hundred grams of platinum are dissolved in aqua regia and the

solution is dried on the sand bath, without, however, producing

decomposition. Though the instructions are not definite, I presume

that the formation of PtCl4 is contemplated.

The dried salt is added little by little to rectified oil of lavender,

placed on a glass paint-grinding plate, and the salt and oil are

ground together with a muller. Care is required to prevent any

appreciable rise of temperature which would decompose the compound

aimed at, and it is for this reason that the salt is to be added

gradually. Of course the absorption of water from the air must be

prevented from taking place as far as possible. Finally, the compound

is diluted by adding oil of lavender up to a total weight of 1400

grams (of oil).

The liquid is poured into a porcelain dish and left absolutely at rest

for eight days. It is then decanted and filtered, left six days at

rest, and again decanted (if necessary). The liquid should have a

specific gravity of 5° on the acid hydrometer. (If by this the Baumé

scale is intended, the corresponding specific gravity would be 1.037.)

A second liquid is prepared by grinding up 25 grams of litharge with

25 grams of borate of lead and 8 to 10 grams of oil of lavender. The

grinding must be thoroughly carried out.

This liquid is to be added to the one first described, and the whole

well mixed. The resulting fluid constitutes the platinising liquid,

and is applied as follows:-

A sheet of clean glass is held vertically, and the liquid is painted

over it, carrying the brush from the lower to the upper edge. The

layer of oil dries slowly, and when it is dry the painting is again

proceeded with, moving the brush this time from right to left; and

similarly the process is repeated twice, the brush being carried from

top to bottom and left to right. This is with the object of securing

great uniformity in the coating. Nothing is said as to the manner in

which the glass is to be dried.

The dried glass is finally heated to a temperature of dull redness in

a muffle furnace. The resinous layer burns away without running or

bubbling, and leaves a dull metallic surface. As the temperature

rises this suddenly brightens, and we obtain the desired surface

(which probably consists of an alloy of lead and platinum). It is

bright only on the surface away from the glass.

I have not had an opportunity of trying this process since I

discovered the detailed account given by Jouglet; but many

modifications have been tried in the laboratory of the Sydney

University by Mr. Pollock, starting from the imperfect note in the

Central Zeitung, which led to no real success.

It was found that it is perfectly easy to obtain brilliant films of

platinum by the following process, provided that the presence of a few

pin-holes does not matter.

The platinum salt employed is what is bought under the name of

platinic chloride; it is, however, probably a mixture of this salt

and hydro-chloro-platinic acid, and has all the appearance of having

been obtained by evaporating a solution of platinum in aqua regia to

dryness on the water bath. A solution of this salt in distilled water

is prepared; the strength does not seem to matter very much, but

perhaps one of salt to ninety-nine water may be regarded as a standard

proportion. To this solution is added a few drops of ordinary gum

water (i.e. a solution of dextrin). The exact quantity does not

matter, but perhaps about 2 per cent may be mentioned as giving good

results.

The glass is painted over with this solution and dried slowly on the

water bath. When the glass is dry, and covered with a uniform hard

film of gum and platinum salt free from bubble holes, it is heated to

redness in a muffle furnace. The necessary and sufficient temperature

is reached as soon as the glass is just sensibly red-hot.

The mirrors obtained in this way are very brilliant on the free

platinum surface. If the gum be omitted, the platinum will have a mat

surface; and if too much gum be used, the platinum will get spotty by

bubbles bursting. There does not appear to be any advantage in using

lead.

It is quite essential that the film be dry and hard before the glass

is fired.

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