Unit 1

THE SCIENTIFIC ATTITUDE

What is the nature of the scientific attitude, the attitude of the man or woman who studies and applies physics, biology, chemistry, geology, engineering, medicine or any other science?

We all know that science plays an important role in the societies in which we live. Many people believe, however, that our progress depends on two different aspects of science. The first of these is the application of the machines, products and systems of applied knowledge that scientists and technologists develop. Through technology, science improves the structure of society and helps man to gain increasing control over his environment. New fibres and drugs, faster and safer means of transport,[1] new systems of applied knowledge (psychiatry, operational research, etc.) are some examples of this aspect of science.

The second aspect is the application by all members of society, from the government official to the ordinary citizen, of the special methods of thought and action that scientists use in their work.

What are these special methods of thinking and acting? First of all, it seems that a successful scientist is full of curiosity—he wants to find out how and why the universe works. He usually directs his attention towards problems which he notices have no satisfactory explanation, and his curiosity makes him look for underlying relationships even if the data available seem to be unconnected. Moreover, he thinks he can improve the existing conditions, whether of pure or applied knowledge, and enjoys trying to solve the problems which this involves.

He is a good observer, accurate, patient and objective and applies persistent and logical thought to the observations he makes. He utilizes the facts he observes to the fullest extent. For example, trained observers obtain a very large amount of information about a star (e.g. distance, mass, velocity, size, etc.) mainly from the accurate analysis of the simple lines that appear in a spectrum.

He is sceptical—he does not accept statements which are not based on the most complete evidence available—and therefore rejects authority as the sole basis for truth. Scientists always check statements and make experiments carefully and objectively to verify them.

Furthermore, he is not only critical of the work of others, but also of his own, since he knows that man is the least reliable of scientific instruments and that a number of factors tend to disturb impartial and objective investigation (see Unit 8).

Lastly, he is highly imaginative since he often has to look for relationships in data which are not only complex but also frequently incomplete. Furthermore, he needs imagination if he wants to make hypotheses of how processes work and how events take place.

These seem to be some of the ways in which a successful scientist or technologist thinks and acts.

[1] *transportation* in U.S.A.

Comprehension

1 Name some sciences.
2 Name two ways in which science can help society to develop.
3 Give some examples of the ways in which science influences everyday life.
4 What elements of science can the ordinary citizen use in order to help his society to develop?
5 How can you describe a person who wants to find out how and why the universe works? curious
6 What is the role of curiosity in the work of a scientist?
7 Name some of the qualities of a good observer.
8 Give an example of how observed facts are utilized to the fullest.
9 How does a sceptical person act?
10 How does the scientist act towards (a) evidence presented by other people, (b) evidence which he presents in his own work?
11 What do you know about the data which the scientist often has to use? How does this affect his way of thinking?
12 For what other purposes does a scientist need imagination?

Word Study
WORD-BUILDING

A common way of making new words in English is by adding standard combinations of letters to existing words, either at the beginning (prefixes) or at the end (suffixes). By noting these carefully, you will find it is easy to make large increases in your recognition vocabulary.

1 The suffix *-ist*

A person who studies and applies
- geology is a geolog*ist*
- biology is a biolog*ist*
- sociology is a ......
- ...... is a chem*ist*
- anthropology is a ......
- ...... is a psycholog*ist*
- archaeology is a ......
- ...... is a ecolog*ist*
- agronomy is a ......

2 The suffix -(*i*)*an*

A person who studies and applies
- mathematics is a mathematic*ian*
- statistics is a ......
- ...... is an obstetric*ian*

But

A person who applies the study of
- economics is an economist
- engineering is an engineer
- architecture is an architect
- medicine is a doctor[1]

[1] Usually *physician* in U.S.A.

3 The suffix *-ion*

This suffix converts a verb into the corresponding noun. The following are some examples which occur in our first passage:

VERB	NOUN
to act	act*ion*
to apply	applicat*ion*
to observe	observat*ion*

More examples of this suffix are given in the Word Study section of Unit 2.

EXERCISE (a) Form nouns from the following verbs:

to imagine; to attract; to direct; to construct; to connect; to relate; to fluctuate.

(b) Form verbs from the following nouns:

conversion; suggestion; production; definition; operation; reduction; population.

NOTE: to join—junction; to destroy—destruction; to query—question; to transmit—transmission.

4 The prefixes *in-* and *un-*

These prefixes are used to make an adjective negative, e.g. '*in*complete' (l. 45) means 'not complete'; '*un*connected' (l. 24) means 'not connected'.

EXERCISE (a) Using *in-*, make the following negative:

accurate; capable; direct; essential; frequent.

(b) Using *un-*, make the following negative:

able; stable; usual; critical; reliable; successful; imaginative; true.

Structure Study

SIMPLE PRESENT TENSE

The main structure in the passage is the Simple Present Tense. Remember that this tense is used:

(i) for actions in the present which happen usually, habitually or generally, e.g. 'He usually *directs* his attention towards problems which he notices have no satisfactory explanation' (ll. 20–21);

(ii) for stating general truths, e.g. 'science *plays* an important role in the societies in which we live' (ll. 4–5); or for stating scientific laws, e.g. Water *freezes* at 0°C.;

(iii) for describing processes in a general way, e.g. A scientist *observes* carefully, *applies* logical thought to his observations, *tries* to find relationships in data, etc.

EXERCISE (a) Fill in the blanks in the following and repeat aloud several times:

I make	accurate experiments	... check	the validity of statements
They ...		... check	
She ...		... checks	
The scientist ...		... check	
Scientists ...		... check	
We ...			
You ...			

I think	logically	... observes	accurately
He ...		... observe	
They ...		... observes	
We ...		... observe	
She ...		... observes	
You ...			

(b) Add as many verbs and appropriate complements as possible, chosen from the passage and the Word Study section, to the following subjects: the scientist, scientists, we,

e.g.

The scientist	USES	reliable instruments
Scientists	USE	
We	USE	

(c) Repeat Exercise (b) above using the same set of verbs and complements, but using new subjects chosen from the passage or the Word Study section, e.g. *Physicists* use reliable instruments.

The Negative The Simple Present Tense forms the negative by the use of *do not* or *does not* before the main verb, e.g.

I, you *do not*	KNOW	the importance of science.
He, she *does not*		
We, they *do not*		

EXERCISE (d) Fill in the blanks in the following and repeat aloud:

I do not accept	incomplete evidence
You ... not accept	unreliable information
We ... not accept	inaccurate statements
A scientist ... not accept	authority in science
They ... not accept	

(e) Repeat Exercise (a) above, using the negative.

The Interrogative The Simple Present Tense forms questions by the use of *do* or *does* before the subject of the main verb, e.g.

Do	I you	
Does	he she	KNOW the importance of science?
Do	we they	

EXERCISE (f) Repeat Exercise (d) above, using the question form.

(g) Put the verbs in brackets into their correct forms:

1 A statistician (apply) mathematics in his work.
2 You (accept) incomplete evidence?
3 The evidence (seem) incomplete.
4 The government official (use) objective methods?
5 Trained observers usually (utilize) data to the fullest.
6 He always (try) to look for underlying relationships in collections of data.
7 A scientist always (think) logically?

SUBSTITUTION TABLES
Simple Present Active

A Affirmatives

1	2	3	4	5	6	7
A scientist A technologist A researcher An investigator	often	uses employs needs	mathematics complex instruments imagination statistical methods new apparatus	in	his	work
They Scientists You Researchers		use employ need			their	

B Negatives

1	2	3	4
A physicist A biologist He An engineer	does not	use employ apply	unreliable instruments inaccurate observation unsuccessful techniques
Scientific workers I We Biochemists	do not		

C. Questions

1	2	3	4	5	6
Does	a specialist an agronomist he a medical worker	some-times	develop require	new	instruments? techniques?
Do	mathematicians geologists they psychologists		need use		methods? ideas?

Discussion and Criticism

1 Do you think there are other special ways of thinking and acting, used by scientists? If so, comment and explain.

2 Do you think some of these ways are more important than others? If so, give reasons.

3 Do you know of any famous scientist whose work demonstrates some or all the qualities mentioned in the passage? Give details.

4 Try to say something about the work of some of the scientists mentioned in the Word Study section.

5 In what ways do other sciences affect the particular science you study yourself? Give examples.

6 Do you agree that it is important to train the non-scientist to think in a scientific way (ll. 14–17). Give good evidence for your point of view.

7 Do you agree that 'man is the least reliable of scientific instruments' (ll. 40–41)? Give examples.

8 Give a clear explanation of what you think the word 'authority' (l. 36) means.

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Unit 3

SCIENTIFIC METHOD AND THE METHODS OF SCIENCE

It is sometimes said that there is no such thing as the so-called 'scientific method'; there are only the methods used in science. Nevertheless, it seems clear that there is often a special sequence of procedures which is involved in the establishment of the working principles of science. This sequence is as follows: (1) a problem is recognized, and as much information as appears to be relevant is collected; (2) a solution (i.e. a hypothesis) is proposed and the consequences arising out of this solution are deduced; (3) these deductions are tested by experiment, and as a result the hypothesis is accepted, modified or discarded.

As an illustration of this we can consider the discovery of air-pressure. Over two thousand years ago, men discovered a method of raising water from one level to another by means of the vacuum pump. When, however, this machine passed into general use in the fifteenth and sixteenth centuries, it was discovered that, no matter how perfect the pump was, it was not possible to raise water vertically more than about 35 feet. Why? Galileo, amongst others, recognized the problem, but failed to solve it.

The problem was then attacked by Torricelli. Analogizing from the recently-discovered phenomenon of water-pressure (hydrostatic pressure), he postulated that a deep 'sea of air' surrounded the earth; it was, he thought, the pressure of this sea of air which pushed on the surface of the water and caused it to rise in the vaccum tube of a pump. A hypothesis, then, was formed. The next step was to deduce the consequences of the hypothesis. Torricelli reasoned that this 'air pressure' would be unable to push a liquid heavier than water as high as 35 feet, and that a column of mercury, for example, which weighed about 14 times more than water, would rise to only a fourteenth of the height of water, i.e. approximately 2.5 feet. He then tested this deduction by means of the experiment we all know, and found that the mercury column measured the height predicted. The experiment therefore supported the hypothesis. A further inference was drawn by Pascal, who reasoned that if this 'sea of air' existed, its pressure at the bottom (i.e. sea-level) would be greater than its pressure further up, and that therefore the height of the mercury column would decrease in proportion to the height above sea-level. He then carried the mercury tube to the top of a mountain and observed that the column fell steadily as the height increased, while another mercury column at the bottom of the mountain remained steady (an example of another of the methods of science, the controlled experiment). This further proof not only established Torricelli's hypothesis more securely, but also demonstrated that, in some aspects, air behaved like water; this, of course, stimulated further enquiry.

Comprehension

1 What does the establishment of the working laws of science often involve?

2 What does a scientist collect when he tries to establish a scientific law? information

3 What is the next step in the process described above? Hypothesis

4 What does the scientist then deduce? Consequences

5 How does he proceed to verify these deductions? By experiments

6 What does he finally do with his original hypothesis?

7 Give an approximate date for the invention of the vacuum pump. 2000 years ago.

8 Is it possible to raise water from the bottom floor of a building to the roof 50 feet above, using a vacuum pump? No Why?

9 What was Torricelli's theory about the height of the water in a vacuum tube?

10 What were his deductions concerning the effect of air pressure on a column of mercury?

11 What further inference was made by Pascal?

12 Why did he use *two* mercury tubes?

13 What were the three results of Pascal's experiment?

14 What do you think happened to the mercury column when it was carried down the mountain? Rise

Word Study

EXERCISE

Using appropriate words chosen from the reading passage, fill in the blanks in the following:

The scientist or technologist uses many m...s when he tries to s... a problem. For instance, an engineer who wants to r... a l... from one l... to another has the choice of several different p...s. One of them is to use a p... which takes the air out of the pipe or t... along which he wants the l... to flow, thus creating a v.... Air p... then pushes on the lower s... of the l... and forces it up the pipe. This method is d...d in the petrol system of a car.[1]

OPPOSITES EXERCISE (a)

From the reading passage choose words which mean the opposite of the following:

shallow (d...p); to lower (to r...e); to rise (to f...l); high (l...w); to succeed (to f...l); to refuse or reject (to a...t); imperfect (p...t); irrelevant (r...t); to pull (to p...h); depth (h...t); horizontal (v...l); to increase (to d...e); seldom (o...n).

(b)

Use the words given above in sentences, using the Present Tense and Present Tense Passive.

WORD-BUILDING

The suffix *-ize*[2]

This forms verbs from nouns and adjectives, and has the meaning: to cause to be or have, or: to subject to a process of, e.g.

analogizing (l. 20) is equivalent to: subjecting (the problem) to a process of analogy.

EXERCISE

By adding *-ize*, form verbs from the following: standard; special; local; pressure; theory; sterile; popular; familiar; neutral; optimum.

NOTE: anal*yse*, from analysis; paral*yse*, from paralysis; mini*mize*, from minimum; maxim*ize*, from maximum; and *utilize*, from use.

In technical literature this suffix is sometimes used with the names of persons or places associated with certain processes, e.g. *macadamize* (road engineering), *pozzuolize* (geology and engineering), and *pasteurize* (food technology).

Structure Study

SIMPLE PAST TENSE

The main structure used in the passage of Unit 3 is the Simple Past Tense. You will probably remember that this is the tense normally used for describing actions which happened in the past and are now finished. With regular verbs the tense is formed by adding *-ed* or *-d* (if the infinitive already ends in *-e*) to the infinitive, e.g.

'Men discover*ed* a method of raising water' (ll. 12–13)

With other subjects, the verb is still in the same form, e.g.

I
You
We
They

discovered] a method, etc.

There are, however, a number of irregular verbs which are frequently encountered, and these have their own special forms of past tense and participle. A list of the most common is given in Appendix B, and should be revised now.

EXERCISE (a) Repeat the first exercise in the Word Study section above, putting the verbs into the Past Tense.

(b) Put the reading passage of Unit 1 (*The Scientific Attitude*) into the Past Tense.

The Negative

The Simple Past Tense, with both regular and irregular verbs forms the negative by the use of *did not* before the infinitive of the main verb; this is the same for all subjects, e.g.

Galileo
I
You
We
They

] *did not* SOLVE the problem of the water-pump

The Interrogative

The Simple Past Tense forms questions by the use of *did* before the subject of the main verb, e.g.

Did [Pascal / I / you / we / they] TEST his inference by means of an experiment?

REVISION EXERCISE

Put the following sentences, which contain irregular verbs, into (i) the Simple Past Tense; (ii) Simple Past Negative; (iii) Simple Past Interrogative:

1 The liquid rises in the tube.
2 The pipes bend under the weight, and break.
3 The aircraft flies faster than sound.
4 The electric motor drives a pump.
5 The engineer takes a lot of measurements.
6 The scientist chooses between several procedures.
7 The hot-water system loses a lot of heat.
8 The lazy schoolboys make an electronic computer.
9 Later, they become famous scientists.
10 We give the results of the calculations in decimals.
11 The experiment takes a long time to carry out.
12 They draw many inferences from the hypothesis.
13 I find the ratio between the numbers.

THE PASSIVE OF THE SIMPLE PAST TENSE

This is used for the same purposes as the Simple Present Passive (see Structure Study section of Unit 2), except that it refers to the past, not the present. It is also formed in the same way, except that *is* and *are* are replaced by *was* and *were* respectively, e.g.

'It *was discovered* that it was impossible to raise water more than about 35 feet' (ll. 15–17)

The problem *was* then *attacked by* Torricelli. (l. 20)

EXERCISE

Put exercises (a) and (b) of the Structure Study section of Unit 2 into the Simple Past Passive.

SUBSTITUTION TABLE

Simple Past Tense

A Affirmatives

1	2	3	4
I	assembled	the electronic unit	last month
We	completed	the apparatus	several weeks ago
He (she)	obtained	a new measuring device	in 1964
They	built	the equipment	some time ago
The technicians	finished	the experimental model	at the end of 1963
Our research group	began work on	the prototype	a fortnight ago
An investigator	tested	a new system	at the beginning of last year

B Negatives

1	2	3	4
He (she)	did not	find the ratio between the two quantities	the last time the experiment was performed
The investigators		obtain the right figures	
The specialist		make any mistakes	
We		give the results in decimals	
The student		set up sufficient controls	
They		see the implications of the problem	
The researcher		write down all the data	

C Questions

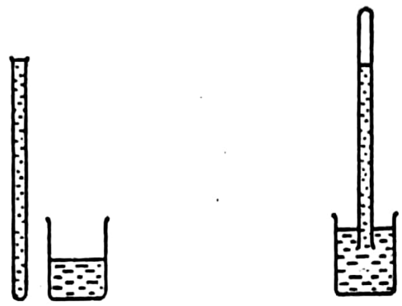
1	2	3	4
Did	you	understand the main problem	in last week's experiments?
	he	spoil a specimen	
	the researchers	choose the most efficient procedure	
	the technician	set up the apparatus correctly	
	they	draw the right conclusions	
	our team	test the new measuring device	
	the students	make any mistakes	

D Passives

1	2	3	4
	some new apparatus a fresh approach an interesting theory	was	developed employed
In the experiments we did last year	some complex instruments several basic concepts many different methods	were	tested

Additional Exercise (for irregular verbs): Put the sentences of Table B above into the Affirmative (i.e. Simple Past Affirmative).

Discussion and Criticism



From the simple diagrams given above, describe Torricelli's famous experiment in a clear and orderly way. This should include his method of forming a vacuum.

2 Draw a simple diagram, or series of diagrams, of an experiment you know. Exchange this with another student (or group): you then describe his experiment, while he explains yours.

3 Torricelli's experiment not only provided support for his hypothesis but also involved the invention of a basic scientific instrument, the barometer. What other basic instruments do you know? How do they work, and what are some of their uses?

4 In the description of scientific method (ll. 5–10), step 2 says 'a solution is proposed'. However, in practice it is common to find that several solutions seem to be equally possible (the multiple hypothesis). How would you proceed in such a case?

5 Given an example of scientific method used in the development of the science you study yourself.

6 Do you agree that there is no *one* scientific method? Give reasons and examples.

7 What do you think is meant by 'as much information as appears to be relevant is collected' (ll. 6–7)? What was the relevant information in Torricelli's case? (Note the developments in hydrostatics.)

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Unit 4

PURE AND APPLIED SCIENCE

As students of science you are probably sometimes puzzled by the terms 'pure' and 'applied' science. Are these two totally different activities, having little or no interconnection, as is often implied? Let us begin by examining what is done by each.

Pure science is primarily concerned with the development of theories (or, as they are frequently called, models) establishing relationships between the phenomena of the universe. When they are sufficiently validated, these theories (hypotheses, models) become the working laws or principles of science. In carrying out this work, the pure scientist usually disregards its application to practical affairs, confining his attention to explanations of how and why events occur. Hence, in physics, the equations describing the behaviour of fundamental particles, or in biology, the establishment of the life cycle of a particular species of insect living in a Polar environment, are said to be examples of pure science (basic research), having no apparent connection (for the moment) with technology, i.e. applied science.

Applied science, on the other hand, is directly concerned with the application of the working laws of pure science to the practical affairs of life, and to increasing man's control over his environment, thus leading to the development of new techniques, processes and machines. Such activities as investigating the strength and uses of materials, extending the findings of pure mathematics to improve the sampling procedures used in agriculture or the social sciences, and developing the potentialities of atomic energy, are all examples of the work of the applied scientist or technologist.

It is evident that many branches of applied science are practical extensions of purely theoretical or experimental work. Thus the study of radioactivity began as a piece of pure research, but its results are now applied in a great number of different ways—in cancer treatment in medicine, the development of fertilizers in agriculture, the study of metal-fatigue in engineering, in methods of estimating the ages of objects in anthropology and geology, etc. Conversely, work in applied science and technology frequently acts as a direct stimulus to the development of pure science. Such an interaction occurs, for example, when the technologist, in applying a particular concept of pure science to a practical problem, reveals a gap or limitation in the theoretical model, thus pointing the way for further basic research. Often a further interaction occurs, since the pure scientist is unable to undertake this further research until another technologist provides him with more highly-developed instruments.

It seems, then, that these two branches of science are mutually dependent and interacting, and that the so-called division between the pure scientist and the applied scientist is more apparent than real.

Comprehension

1 What is often implied by the terms 'pure' and 'applied' science?
2 What is the aim (object) of pure scientific investigation?
87 3 Name some examples of basic research.
8 4 How are the working laws of science established?
5 What is the work of an applied scientist?
6 Name some examples of applied science.
7 Name some applications of radioactivity.
88 8 Name some examples of the interaction of pure and applied science.
9 Give two other words meaning the same thing as hypothesis.

Word Study

EXERCISE

Complete the following sentences, choosing *one* of the four expressions in the brackets:

1 The results of research into radioactivity are applied in (electronic computers; sampling procedures; cancer treatment; pure science).

2 Many branches of applied research developed out of (the work of technologists; pieces of basic research; equations describing the behaviour of fundamental particles; new processes).

3 Pure science relates to (more highly-developed instruments; sampling procedures; solving practical problems; developing theories which explain the relationships between phenomena).

4 New kinds (types) of instruments are frequently essential for (developing basic research; improving fertilizers in agriculture; describing the life cycles of insects; finding the cube root of fractions).

5 Investigating the strength and uses of materials is an example of (the principles of pure science; technology; the interaction of basic and applied research; a theoretical model).

NOUNS AND THEIR ASSOCIATED VERBS

To use a language properly, it is important to know not only the names of things (nouns) but also the names for the actions that are associated with them (verbs): the actions are as important as the objects. Here is a list of the verbs connected with some important nouns appearing in this unit and also Units 1 and 2:

to obtain [evidence / knowledge / information / results]

to [invent / design / develop / modify] [a machine / an instrument / a process / a technique]

Comprehension

1 What is often implied by the terms 'pure' and 'applied' science?

2 What is the aim (object) of pure scientific investigation?

3 Name some examples of basic research.

4 How are the working laws of science established?

5 What is the work of an applied scientist?

6 Name some examples of applied science.

7 Name some applications of radioactivity.

8 Name some examples of the interaction of pure and applied science.

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To use a language properly, it is important to know not only the names of things (nouns) but also the names for the actions that are associated with them (verbs): the actions are as important as the objects. Here is a list of the verbs connected with some important nouns appearing in this unit and also Units 1 and 2:

to obtain	evidence	to	invent	a machine
	knowledge		design	an instrument
	information		develop	a process
	results		modify	a technique

to	design, plan make, perform, conduct, carry out control time repeat	an experiment

to	develop suggest prove, validate disprove modify discard support put forward test	a theory a hypothesis

EXERCISE (a) Complete the following sentences with suitable verbs from the above tables:

1 A scientist must ... adequate evidence to ... a theory.

2 We must ... many experiments in order to ... a new process.

3 If an experiment is not successful, we must ... it.

4 An experiment must be carefully ...ed if we want it to ... a theory properly.

5 Technologists ... new machines to increase production.

6 If a series of carefully ...ed experiments dis... a hypothesis, we should ... it.

7 Engineers ... experiments to ... information about the strength of materials.

8 When new instruments are ...ed, the scientist is able to ... further experiments which frequently have the result of ...ing or ...ing well-established theories.

(b) What verbs are associated with the following nouns? (They all appear either in this unit or Units 1 and 2):

a problem; observations; research; a statement; relationships; mathematical operations.

WORD-BUILDING

1 The suffix *-al*. This forms adjectives from the corresponding nouns, e.g. 'practic*al*' (l. 11) from *practice*, 'theoretic*al*' (l. 29) from *theory*. Adjectives from the names of sciences ending in *-ics* also take this suffix, e.g. mathematics—mathematic*al*.

NOTE: theory—theor*etical*; geometry—geomet*rical*; hypothesis—hypoth*etical*; techni*que*—techni*cal*; machine—mech*anical*; centre—cent*ral*; air—a*erial*; cycle—cycl*ical*.

EXERCISE Form further adjectives from the following:

addition; condition; experiment; nature; neuter; operation; section; region; analysis; matter.

2 The prefix *inter-*. This is added to verbs and derivatives to give the extra meaning of: between, among, one with the

EXERCISE (a) Form adjectives from the following:
dependent; related; national.

(b) Form verbs from the following, using the prefix *inter-* in all cases:
act; breed; change; connect.

Structure Study

THE *-ing* FORM (I)

The main structure used in the passage of Unit 4 is the *-ing* form of the verb. This is frequently used by scientific writers because of its conciseness and flexibility, and is employed in a number of different ways. Note the following examples:

(i) 'Are these two totally different types of activity, *having* ... no interconnection?' (l. 2)
'The equations *describing* the behaviour of fundamental particles.' (l. 12)
In both these cases the *-ing* form takes the place of a longer phrase with *which*, *who* or *that*. Thus in the first example *having* is equivalent to *which have*; in the second, *describing*—*which describe*.[1]

(ii) 'Such activities as *investigating* the strength ... of materials, *extending* the findings of pure mathematics ... and *developing* the potentialities of atomic energy ...' (ll. 22–26)
Here, the *-ing* form takes the place of the derived noun: *investigating* = *the investigation of*, *extending* = *the extension of*, etc.

(iii) 'These theories ... become the *working* laws of science.' (l. 8).
'These two branches of science are mutually dependent and *interacting*.' (l. 45–46)
In the above examples, the *-ing* structure is used as an adjective describing (which describes) the noun it is associated with.

(iv) 'Let us begin by *examining* what is done by each.' (l. 4).
'(Radioactivity is applied) in methods of *estimating* the ages of objects.' (l. 34)
Note that in these cases the *-ing* form follows a word like *by*, *of*, *with*, *from*, *in*, etc. (prepositions). Many nouns, verbs and adjectives are associated with prepositions that complete their meaning, and any verb following (which follows) these prepositions takes the *-ing* form.

(v) 'The technologist, in *applying* a particular concept of pure science ... reveals a ... limitation in the theoretical model.' (ll. 38–39).
Here the *-ing* form is used, in association with a preposition, in place of a longer phrase with a noun or verb. Thus in the example given above, *in applying* is equivalent to: during the process of the application of ...

[1]A slightly different case occurs in l. 11, where the verb '*confining*' refers to 'the pure scientist', and is equivalent to the phrase '*and confines*'.

NOTE: The *-ing* form is also used in two additional cases which are not illustrated in passage 4. These are:

(vi) As part of the Continuous (Progressive) Tenses,

(vii) After certain verbs, such as *avoid.*

These uses are illustrated in Units 6 and 7 respectively.

Focus your attention for the moment on the first two uses demonstrated above:

1 As a replacement of (replacing) a phrase with *who, which* or *that*

EXERCISE (a) Find further examples of this use in the passage.

(b) In the following sentences, replace the phrases in italics with the appropriate *-ing* form:

1 A person *who does* research in chemistry is called a research chemist.

2 The research scientist often comes across problems *that require* new types of instrument for their solution.

3 New types of instrument frequently lead to discoveries *which modify* the basic principles of science.

4 Scientists sometimes develop theories *which affect* other human activities such as morals or religion. (Do you agree that morals and religion are 'activities'?).

5 Technologists develop new techniques *which increase* man's control over his environment.

6 Theories *that describe* the nature of the universe are constantly revised by scientists.

7 The force *that holds* the solar system together is gravitation.

8 The total amount of chemical reactions *that take* place in a living organism is its metabolism.

9 Viruses are entities *that occupy* a position between living and non-living matter.

10 Scale models *that reproduce* the behaviour of flowing water are used in hydraulics research.

11 Some rockets use liquid fuels *that consist* of oxygen and kerosene.

12 Newton described the laws *that govern* the motion of falling bodies.

2 Replacing a noun

EXERCISE (a) Find further examples of this use in this passage and also in the passage of Unit 1 (*The Scientific Attitude*).

(b) In the following passage replace the word or phrase in italics by the appropriate *-ing* structure:

The work of the technologist is *the application of* the theories of the research scientist, *the development of* new processes, *the invention of* new machines and *the extension of* the uses of techniques *which exist* already. It is often difficult to separate his work from some of the activities *which belong* to the pure scientist, such as *the design of experiments* and *the elaboration of* hypotheses.

Discussion and Criticism

1 How are the following sciences applied for technological purposes: geology; meteorology; chemistry; psychology? Give details.

2 Do you agree that many pieces of applied research began as pure science? (ll. 28-29) Give examples.

3 Name some materials used in engineering. Why is it important to test their strength?

4 Give any details you know about an inventor and his work, and if possible, about its connection with basic research.

5 Do you know any examples of an advance in the field of pure science which was dependent on the development of new instruments? (ll. 41–44).

6 Give examples of how the following are applied in the discipline you study yourself: radioactivity; statistics; optics; electricity; magnetism; psychology.

7 Do you agree with the conclusions of the last paragraph (ll. 45–48). Give reasons for your answer.

8 Radio, television (TV) and films often give a favourable picture of the pure scientist, and an unfavourable one of the applied scientist (excluding doctors). Is this true in your own country? Why? Give your own opinion in the matter.

9 Give examples of man's increasing control over his environment.

Unit 5

(Revision of material appearing in Units 1–4)

'DIRECTED' RESEARCH? (organized or programmed research)

A recent phenomenon in present-day science and technology is the increasing trend towards 'directed' or 'programmed' research; i.e. research whose scope and objectives are predetermined by private or government organizations rather than researchers themselves. Any scientist working for such organizations and investigating in a given field therefore tends to do so in accordance with a plan or programme designed beforehand.

At the beginning of the century, however, the situation was quite different. At that time there were no industrial research organizations in the modern sense: the laboratory unit consisted of a few scientists at the most, assisted by one or two technicians, often working with inadequate equipment in unsuitable rooms. Nevertheless, the scientist was free to choose any subject for investigation he liked, since there was no predetermined programme to which he had to conform.

As the century developed, the increasing magnitude and complexity of the problems to be solved and the growing interconnection of different disciplines made it impossible, in many cases, for the individual scientist to deal with the huge mass of new data, techniques and equipment that were required for carrying out research accurately and efficiently. The increasing scale and scope of the experiments needed to test new hypotheses and develop new techniques and industrial processes led to the setting up of research groups or teams using highly-complicated equipment in elaborately-designed laboratories. Owing to the large sums of money involved, it was then felt essential to direct these human and material resources into specific channels with clearly-defined objectives. In this way it was considered that the quickest and most practical results could be obtained. This, then, was programmed (programmatic) research.

One of the effects of this organized and standardized investigation is to cause the scientist to become increasingly involved in applied research (development), especially in the branches of science which seem most likely to have industrial applications. Since private industry and even government departments tend to concentrate on immediate results and show comparatively little interest in long-range investigations, there is a steady shift of scientists from the pure to the applied field, where there are more jobs available, frequently more highly-paid and with better technical facilities than jobs connected with pure research in a university.

Owing to the interdependence between pure and applied science (see Unit 4), it is easy to see that this system, if extended too far, carries considerable dangers for the future of science—and not only pure science, but applied science as well.

Comprehension

1 What is programmed research?

2 What differences in working conditions are there between

Indispensible — Absolutely essential eg. air, water,

the present-day scientist and scientists working at the beginning of the century?

3 Describe laboratory conditions at the beginning of the century.

87 86 4 What were the origins of programmed research?

5 Why is it difficult nowadays for the individual scientist to make significant contributions to science?

6 Mention one of the effects of organized research on the attitudes of scientists.

7 What is a common attitude of private industry and government departments towards scientific investigation?

8 What part does money play in the situation discussed in the passage?

89 9 How is the situation likely to affect the future of science?

10 Give another word meaning the same as 'applied science'. (Te

11 Give two other words for 'directed' research.

(Programmed, Programmatic, organized, Standardized,

Word Study Revision

EXERCISE (a) The reading passage contains numerous examples of suffixes and prefixes used in Units 1–4. Pick these out, and give the meaning of the prefix or suffix in each case.

unsuitable unlikely infrequent (rare)

(Imp.) **(b)** Give the opposites of: suitable; likely; frequent; limited; essential; able; efficient.

unlimited

unnecessary unable inefficient

(c) In the following sentences, use a verb with *en* as a prefix or suffix to replace the expression in italics:

1 They *increase the length of* the pipe.

2 We *made* the road *wider*.

3 The engineers *increase the strength of* the bridge.

4 That government department plans to *make* its laboratories *larger*.

5 The tube was *made shorter*.

6 The high temperature had the effect of *making* the metal *softer*.

7 The softening of the metal had the effect of *making* the whole structure *weaker*.

(d) Add the appropriate suffixes to form the names of specialists in the following scientific disciplines: archaeology; obstetrics; ecology; agronomy; economics; physics; statistics.

(e) Using nouns formed from verbs given in the exercises in Unit 1, complete the following:

1 The po...ion of England is about 50,000,000.

2 Governments talk about a re...ion of nuclear armaments.

3 There is a close re...ion between pure and applied science.

4 The use of radio was responsible for a great increase in the speed of tr...ion of messages.

5 What are the main op...ions of arithmetic?

6 Many new devices were used in the co...ion of the latest type of computer.

7 Atmospheric pressure varies considerably, but these fl...ions can be recorded by means of a barograph.

(f) Using nouns formed in the appropriate exercise of Unit 2, complete the following:

1 The accurate me...ment of quantities is very important in science.

2 A good scientist is highly critical of his own st...ments.

3 Scientific instruments and machines frequently need ad...ment before they are used.

4 The de...ment of scientific e...ment is a specialized process.

5 Experimental methods often lead to the es...ment of working principles or laws.

6 One of the aims of programmatic research is the im...ment of industrial techniques.

(g) Give the opposites of: tight; to raise; deep; often; horizontal; regular; to increase.

Structure Study Revision 1 Simple Present Tense

EXERCISE (a) Make the following sentences interrogative:

1 She wants to know the answer to the problem.

2 He carries out experiments.

3 Some scientists use complex procedures.

4 He tests his theory very carefully.

5 Good laboratory conditions act as a stimulus to research.

6 The scientist applies persistent and logical thought to his problems.

7 The experiments reveal a limitation in the theoretical model.

(b) From the above sentences, choose appropriate ones only (i.e. that make sense) to put in the negative.

2 Simple Present Passive

EXERCISE (a) Put the following sentences into the passive (decide whether an agent with *by* is necessary or not):

1 People use mathematics in all branches of science.

2 People apply scientific methods in many everyday activities.

3 People obtain a great deal of useful knowledge from the study of nature.

4 People usually use the decimal system for scientific purposes.

5 People control experiments to obtain accurate results.

6 People obtain accurate results from controlled experiments.

7 Different kinds of people often make attempts to deceive the ordinary citizen.

(b) Put the following sentences into the passive (decide whether an agent with *by* is necessary or not):

1 Government departments apply programmed research on an increasing scale nowadays.

2 Specialized technicians develop modern scientific instruments.

3 The work of the technologist frequently helps the basic scientist.

4 Nowadays social scientists investigate an increasingly wide range of problems.

5 An electric pump raises the water.

6 Geologists use radioactivity as a means of dating rocks.

7 Scientists require very strong evidence before they accept a theory.

3 Simple Past Tense

EXERCISE (a) Put the following into the Simple Past Tense:

1 The bridge bends under its own weight.

2 The electric motor drives the pump.

3 The scientist chooses between several possible solutions.

4 The Torricelli experiment becomes famous.

5 The engineers find a new method of testing metal-fatigue.

6 The water in the pump rises.

7 The pressure falls slightly.

(b) Repeat the following paragraph, putting all the verbs into the Simple Past Tense:

The geochemist goes to sea in a ship equipped with special pipes. Technicians then push these pipes through thousands of feet of water until they strike the bottom (bed) of the ocean. Then they drive the pipes into the sea-bottom, and when they bring them up again they are full of mud. The geochemist takes it to his laboratory and examines it carefully. This mud gives him evidence about the constitution of the rocks of the earth.

4 Simple Past Passive

EXERCISE **Put the sentences of 2, Exercises (a) and (b) above into the Simple Past Passive.**

5 The *-ing* form of the verb

EXERCISE (a) The reading passage gives various examples of the *-ing* form. Pick these out, and replace them, where possible, by another structure having the same meaning.

(b) Replace the phrases in italics by an *-ing* form:

1 Air *that pushes* on the surface of the water causes it to rise in a vacuum pump.

2 Liquids *which weigh* more than water rise less in a vacuum tube.

3 The pressure *that exists* at the bottom of the ocean is greater than that on the surface.

4 Experiments *which proved* the effects of air pressure were conducted by Torricelli and Pascal.

5 Numbers *that consist* of digits are called integers.

6 Statistics is a discipline *which affects* all the other sciences.

7 The technologist is concerned with *the development of* new processes and techniques.

Discussion and Criticism

1 Give examples of programmed research in any field.

2 Give examples of types of research which it is difficult for a single scientist, working alone, to carry out.

3 Describe any cases you know of an individual scientist contributing to the advance of science.

4 Why does private industry want immediate results for its research?

5 Explain the last paragraph of the passage. Why may programmed research become a danger to the future of applied research? What is your own opinion?

6 To what extent is research directed or programmed in your country? Give details.

7 Do you think any research should be directed? If so, what kinds, and to what degree? Give good reasons for your answers.

8 What are the arguments for and against allowing scientists complete freedom to do the research they want to do, rather than what the Government, or some other outside person or organization, consider to be important?

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Unit 8

SOURCES OF ERROR IN SCIENTIFIC INVESTIGATION

In Unit 3 we examined briefly the sequence of procedures which make up the so-called scientific method. We are now going to consider a few of the many ways in which a scientist may fall into error while following these procedures.

In formulating hypotheses, for example, a common error is the uncritical acceptance of apparently common-sense, but untested, assumptions. Thus in the field of psychology it was for many years automatically assumed that the main cause of forgetfulness as the interval of time elapsing between successive exposures to a learning stimulus. Experimentation, however, was subsequently undertaken, and several other factors, such as motivation and the strength or effectiveness of the stimulus, turned out to have an even more important bearing on the problem. A somewhat similar error arises from neglect of multiple causes. Thus two events may be found to be associated, e.g. when the incidence of a disease in a smoky industrial sector of a city is significantly higher than in the smoke-free zones. A research worker might infer that the existence of the disease is due to the smokiness of the area when in fact it might equally well be found in other reasons, such as the under-nourishment of the inhabitants or over-crowding.

Both in collecting the original evidence and in carrying out subsequent experiments, a frequent cause of error is the fact that observations are not continued for a long enough time. This may lead not only to a failure to discover positive items (e.g. Le Monnier's failure to recognize that Uranus was a new planet, not a fixed star, etc.), but may also result in important negative aspects of the investigation remaining undiscovered. In applied science, this latter error may have disastrous consequences, as in the case of the thalidomide drugs, cancer-inducing industrial chemicals, etc.

Another well-known error in experimentation is lack of adequate controls (see Unit 3, ll. 39–43). Thus a few years ago it was widely believed that a certain vaccine could prevent the common cold, since in the experiments the vaccinated subjects reported a decrease in the incidence of colds compared with the previous year. Yet later, more strictly-controlled experiments failed to support this conclusion, which could have been due to a misinterpretation of chance results. This error is often caused by a failure to test a sufficient number of subjects (inadequate sampling), a disadvantage which affects medical and psychological research in particular.

Errors in measurement, particularly where complicated instruments are used, are common: they may arise through lack of skill in the operator or may be introduced through defects in the apparatus itself. Furthermore, it should be borne in mind that apparently minor changes in laboratory conditions, such as variations in the electric current, or failure to maintain atmospheric conditions constant, may disturb the accuracy of various items of equipment and hence have an adverse influence on the experiment or series of experiments as a whole. In addition, such errors tend to be cumulative.

Finally, emotion in the observer can be one of the most dangerous sources of error. This may cause the researcher to over-stress or attach too much importance to irrelevant details because of their usefulness in supporting a theory to which he is personally inclined. Conversely, evidence disproving the view held may be ignored for similar reasons. Even routine matters such as the recording of data may be subject to emotional interference, and should be carefully checked.

To sum up (summarize), the multiple possibilities of error are present at every stage of a scientific investigation, and constant vigilance (care) and the greatest foresight must be exercised in order to minimize or eliminate them. Additional errors are, of course, connected with faulty reasoning; but so widespread and serious are the consequences that may arise from this source that they deserve separate treatment in the following unit.

Comprehension

1 What is the connection between the reading passage in this unit and that of Unit 3?

2 At what stage of an investigation is the scientist most likely to commit the error of accepting untested assumptions?

3 Give an example of this type of error.

4 What type of error is similar to the above?

5 Name at least three factors that an unduly high incidence of disease in a smoky sector of a city might be due to.

6 Name two broad results that insufficient observation may lead to. Give examples of each.

7 Why was it believed that a certain vaccine could cure the common cold?

8 What is meant by *inadequate sampling*? inadequate subjects are used

9 Name two causes of inaccurate measurements.

10 What other factors can affect the accuracy of instruments?

11 What is an additional danger in these so-called minor errors?

12 Name three ways in which emotion can cause scientists to make mistakes.

13 How can the possibilities of error be minimized?

14 What is the last source of error named in the passage?

Word Study

WORDS WITH DIFFERENT MEANINGS FOR THE SAME FUNCTION

A word may sometimes have more than one meaning though its function (i.e. whether it is a noun, an adjective, etc.) remains the same. An example in the reading passage is the word *constant*, which in l. 49 is equivalent to *unaltered*, whereas in l. 62 its meaning is *continuous*.

EXERCISE (a) Look up the following words in the Basic Dictionary, and note their different meanings:

to mount; power; matter; drop; plant; beam; chart; light (adj.).

(b) Complete the following sentences with words in their appropriate meanings chosen from Exercise (a) above:

1 The chart ... compiled by a hydrographer is different from the one a statistician uses.

2 The *Annual Bulletin* of the Department of Mines reports that there has been a ... in the production of metals during the current year.

3 The experimenters noted that the crystalline structure of the material under study was altered as the pressure ...ed. mounted

4 In mathematics a quantity successively multiplied by itself is said to be raised to a power. Thus 4 × 4 × 4 is 4 raised to the third power.

5 Lasers are modern optical devices capable of transmitting an extremely narrow and powerful beam of light.

6 In modern engineering, the beam ...s used for supporting roofs are no longer made of wood, but of other materials which are stronger and lighter.

7 The laboratory specimen was mounted ...ed on a slide for microscopic analysis.

8 Electrical power ... can be generated by machines driven by the energy of moving or falling water.

9 It is a well-known fact that buildings, etc., painted in light colours tend to reflect solar heat, while those painted in dark colours tend to absorb it.

10 The origin of life on earth is still largely a matter ... of speculation since no certain knowledge is available.

11 In view of the likely exhaustion of natural fuels, nuclear energy is being used for generating electricity and several countries have set up nuclear power ...s.

12 In the process of condensation, water vapour in the atmosphere cools off and condenses (i.e. it becomes liquid) around dust particles to form ...s of water which fall on the land as rain. drqu

WORD-BUILDING

1 The suffixes *-ent* (*-ant*) and *-ence* (*-ance*). Whilst the suffix *-ent* (*-ant*) is added to verbs to form corresponding adjectives, e.g. suffici*ent* (l. 40) from the verb *to suffice*, the suffix *-ence* (*-ance*) turns both verbs and adjectives into the corresponding abstract nouns, e.g. accept*ance* (l. 6), meaning the action of accepting, exist*ence* (l. 18), meaning the quality of existing, import*ance* (l. 55), meaning quality of being important, etc.

EXERCISE (a) Using an English-English dictionary, and following the examples given in the first line of the table given below, supply the correct words in place of the question-marks (?)

persist	persistent	persistence
resist ?	resistant	resistence
signify	significant	? significance
consequent	consequent	consequence.
ignore	ignorant	ignorance
interfere	inference ?	? interference
convenient.	?	convenience
depend	dependent	? dependance.
—	evident	evident
—	present	presence
diverge	divergent	? divergence.
differ	different	? difference.
?	emergent	?
disturb	disturbant	? disturbance
?	?	assistance
—	?	permanence
?	—	performance
?	convergent	?
—	resonant	?
—	?	absence

(b) From the table completed in Exercise (a) above, choose appropriate adjectives and nouns to fill in the blanks in the following sentences:

1 The em… of new nations has given rise to further international problems.

2 Economic growth leads to increased interd… between nations.

3 Agricultural researchers are now producing plants which are much more r… to disease and adverse atmospheric conditions than hitherto.

4 Economic instability may lead to political d…s.

5 If a researcher encounters dif…s between two parallel experiments, he has to find out whether they are s… or not.

6 Laboratory equipment must be designed to give a high level of p….

7 An investigator should do his best to isolate his experiments from in… due to chance or random factors.

8 It may sometimes be difficult for the investigator to determine the exact degree of relevance of the ev… he has collected.

2 The suffix *-er* (*-or*). This suffix, and its variant, forms nouns from verbs, with the general meaning of: person or thing which *-s*, e.g. work*er* (l. 5), operat*or* (l. 45), oberv*er* (l. 53) and research*er* (l. 54). Although usually referring to persons, the words so formed may also refer to things, e.g. a steriliz*er* is an apparatus for sterilizing instruments, a conduct*or* is something which conducts heat or electricity, etc.

EXERCISE (a) Add *-er* to the following verbs to form corresponding nouns:

boil; breed; count; contain; convert; enlarge; fill; produce; start; train; transmit; transform.

(b) Add *-or* to the following verbs to form corresponding nouns:

demonstrate; direct; insulate; investigate; react; indicate.

Use the words formed above in sentences of your own.

3 The prefixes *over-* and *under-*. *Over-* placed in front of a word gives the idea of excess, e.g. *over*crowding (l. 21) means excessive crowding; to *over*stress (l. 55) means to lay too much stress on. Its opposite, *under-*, gives the idea of insufficiency or inadequacy, as in *under*-nourishment (l. 20), meaning lack of sufficient nourishment.

EXERCISE (a) Put *over-* in front of the following words, and explain the expressions thus formed:

to load; to heat; acceleration; production; population; to supply; to cultivate.

(b) Put *under-* in front of the following words, and explain the expressions thus formed:

to estimate; to feed (nourish); industrialization; size; weight.

4 The suffix *-ness*. This suffix forms abstract nouns from adjectives, e.g. forgetful*ness* (l. 9), effective*ness* (l. 12), and useful*ness* (l. 56).

EXERCISE (a) Form abstract nouns from the following:

clear; cool; cold; damp; dark; direct (indirect); exact; flat; full; heavy[1]; quick; rough; shallow; sharp; short; slow; steady (unsteady); steep; thick; thin; tight; weak; light.

(b) Complete the following by choosing the appropriate words from those in 2, 3 and 4 above.

The research ...er in the field of economics who investigates the phenomenon of under... productio, which leads emerging countries to rely almost exclusively on the export of raw materials for their foreign exchange, often finds that for this reason—and also to satisfy the growing demands caused by over...—both the produ ...ers of crops and the b...ers of animals tend to over... cultivate the land. This may lead to a steady decrease in soil fertility and is thus a cause of great weakness ...ness in the economies of such regions. On the other hand, especially favourable climatic conditions may lead to the over... product of raw materials, with a consequent drop in the export price. All these factors help the investigat ...or to explain the steadi ...ness and un... steady ...ness with which these countries develop, in the absence of industrialization.

Structure Study

The reading passage incorporates further examples of the *anomalous finites* first presented in Unit 7 (Structure Study

[1] Adjectives ending in *y* change to an *i* in the noun.

section, para. 1). These are words such as *may, might, can, could (be able), must (have to),* and *should (ought to)*, which are used with the *infinitive* of a verb to modify that verb by attaching different meanings to it, as follows:

1 CAN (am, are, is ABLE)—past tense COULD (was, were ABLE). These anomalous finites convey the idea of *physical or mental ability*,

e.g. ll. 53–54. 'Emotion in the observer *can* be one of the most dangerous sources of error.'

2 COULD. Apart from forming the past tense and conditional (= would be able) of 'CAN' (see above), *could* may sometimes indicate *possibility* in the present or past, and is thus equivalent to MAY or MIGHT,

e.g. ll. 38–39: 'This conclusion *could* have been due to a misinterpretation of chance results.'

3 MAY—past tense MIGHT. In scientific English, these anomalous finites indicate *possibility*,

e.g. l. 15: 'Thus two events *may* be found to be associated ...'

4 MIGHT. In addition to forming the past tense of MAY (see above), *might* can also convey the idea of a *more remote possibility* in present and future than *may*,

e.g. ll. 18–19: 'A research worker *might* infer that the disease was due to the smokiness of the area.'

5 MUST (HAVE TO)—past tense: HAD TO. These anomalous finites indicate *necessity or compulsion*,

e.g. ll. 63–64: 'The greatest care *must* be exercised in order to eliminate errors.'

6 SHOULD (OUGHT TO). These anomalous finites (the same for all tenses) convey the idea of *moral obligation*, and are therefore less compulsive than *must*,

e.g. ll. 59–60: 'The recording of data may be subject to emotional interference, and *should* be carefully checked.'

As an extension of this idea, scientific writers frequently employ these two anomalous finites, especially SHOULD, to convey the idea of *expectation*, i.e. as a substitute for the phrase: it can be expected that,

e.g. The use of higher-octane fuels in internal-combustion engines *should* result in improved performance.

NOTE: The future tense of *can* is WILL BE ABLE TO and of *must* is WILL HAVE TO.

EXERCISE

Complete the passage below, putting the appropriate anomalous finites in the spaces according to the ideas given in brackets:

In addition to the errors mentioned in the reading passage, a scientific researcher may ... (*possibility*) commit other mistakes. For example, he might ... (*remote possibility*) fail to read all the relevant literature about the problem he is investigating, and so might ... (*remote possibility*) miss essential pieces of evidence. Or, in designing an experiment or set of experiments, he may ... (*possibility*) even incorporate the answer he expects or subconsciously desires. This can ... (*physical ability*) easily happen, especially in the fields of psychology or sociology where the questionnaire method is extensively used; the investigator must ... (*necessity*) be extremely careful, in framing the questions, to avoid influencing the replies of the subjects who are to answer them. To understand—and therefore avoid—these, and similar errors, the student ... (*moral obligation*) read the detailed accounts of the major scientific discoveries of the past, and wherever possible he ... (*moral obligation*) try to find out the true stories of the development of pieces of modern research by talking to the successful investigators concerned. If this procedure is followed, he may ... (*expectation*) greatly increase his chances of becoming a successful worker himself.

SUBSTITUTION TABLE
Anomalous Finites

A Ability, possibility

1	2	3	4
Untested assumptions Faulty equipment Insufficient observations Inadequate sampling	can obviously could easily may possibly might, if uncorrected,	lead to result in give rise produce	false generalizations invalid data to erroneous conclusions disturbing effects in a piece of research

B Obligation, advisability, compulsion

1	2	3	4	5	6
Special care Critical judgement Strict objectivity Logical thought	ought, as a matter of course, should advisedly must necessarily has obviously	to be	exercised used applied	in	analysing course results developing new theories

Discussion and Criticism

1 Can you suggest why medical and psychological researchers (rather than, say, entomologists) are liable to fall into the error of inadequate sampling (ll. 40–43)?

2 Explain clearly what is meant by 'lack of adequate controls' (ll. 32–33).

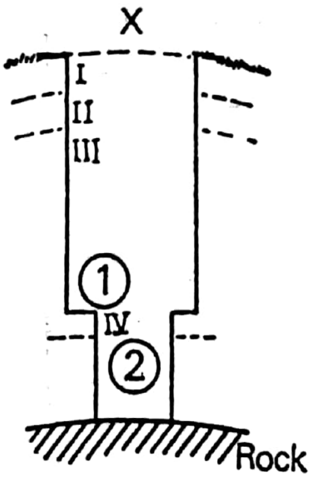
3 Explain clearly how insufficient observation (ll. 22–28) has led to a failure to reveal weaknesses in a theory or piece of applied research. As examples of the latter, you could consider (a) the thalidomide drugs; (b) cancer-inducing industrial chemicals; (c) modern pesticides and their often disastrous side-effects; (d) aircraft or other engineering failures; (e) any other examples you know or can find out for yourself.

4 Give concrete examples of each of the errors mentioned in the reading passage or the exercise given in the Structure Study section.

5 Explain why the last line of the exercise in the Structure Study section recommends the student to try and find out the *true* stories of pieces of successful research. Why may these differ from the published accounts of the investigations?

6 Can you think of any further sources of error *not* mentioned in the unit? Try to give specific examples wherever possible.

7 The following are two different accounts of archaeological investigations at the same site (place). Study them both critically, and answer the questions attached:



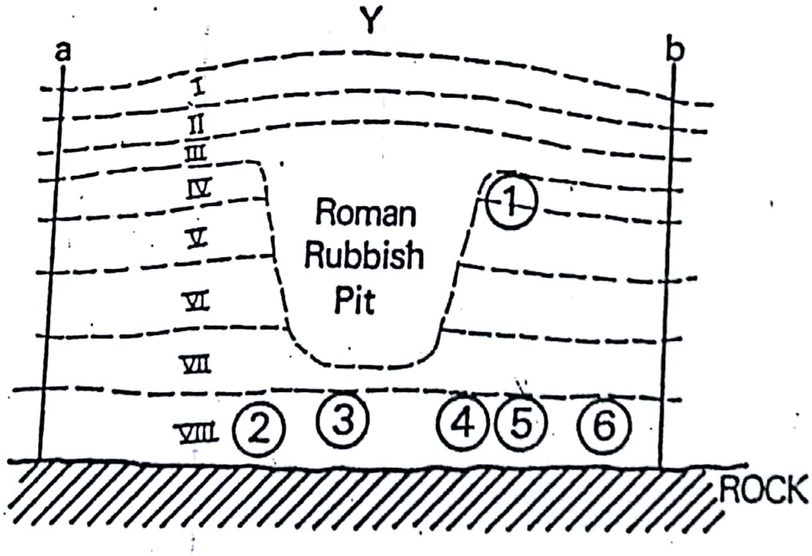
Excavation X

This was carried out by Mr Xcentric, who had been given funds by a well-known newspaper to excavate a site in the Middle East where written records indicated that a Roman settlement might have existed. He arrived on the site rather late in the season, and partly for this reason, partly because he knew the newspaper wanted quick results, he sank a shaft straight down from the top of one of the mounds (see cross-section above). He found traces of a 12th-century local settlement on top (I), then an unoccupied level (II), then abundant Roman artefacts, most of them broken, as well as layers of ashes. At 1 he found a Roman coin of the 2nd century A.D. Below this he found another unoccupied level (IV), but decided he would sink a small shaft down to bed-rock to see if there were traces of further occupation. His enterprise was rewarded, and at (2) he found a human bone. As he had to go on to South America almost immediately in order to do another excavation for another newspaper, he sent the bone to a local university to be dated by chemical methods. This was done, and was given an age of c. 6500 years, which corresponded fairly well with the dates of Neolithic settlements in a neighbouring country. Although rather surprised at the length of the Roman occupation implied by the depth of the layer of Roman remains, he sent his newspaper the following reconstruction:

'The site was originally settled by a Neolithic settlement, whose occupation terminated about 4500 B.C. These early inhabitants were probably primitive hunters, as no tools were found in this level. After a period of disuse, the site was occupied by the Romans, not earlier than the 2nd century A.D. This occupation continued for a considerable time, and it is presumed that, like the 'Lost Legions' of Africa, this isolated settlement kept alive the civilization of Rome for many centuries after the Roman Empire had disappeared. The many broken artefacts recovered—some of them showing traces of fire—as well as the layers of ashes indicate that the settlers suffered frequent attacks from the local inhabitants, until the end came some time before the 12th century A.D.'

Excavation Y

This was carried out by Mr Yse, an expert on Roman occupations who read Mr Xcentric's newspaper report and was also surprised at the length of the presumed Roman occupation. He



was able to persuade a benevolent Foundation to give him some money for further investigation. He thereupon chose a mound next to the one investigated by Mr Xcentric, and began to remove one by one the layers of occupation between *a* and *b*, with the results given in the cross-section:

Level I was the local 12th-century settlement; II was unoccupied; III showed traces of Roman occupation, from about the middle of the second to the beginning of the third century A.D.; IV was again unoccupied, and V showed a Scythian settlement. Throughout VI some beautifully-made stone tools, including a number of sickles for cutting crops, were found. VII was unoccupied, and at VIII human bones were found at ②, ③, ④, ⑤ and ⑥, together with a few very primitive stone tools, including a pestle and mortar. The bones were sent to Europe for dating, with the following average results for each specimen:

② 11,100 years; ③ 6,800 years; ④ 10,200 years; ⑤ 10,100 years; ⑥ 10,400 years.

At ① a broken stone sickle was found.
Mr Yse noted that the bone specimen found at ③ was directly underneath the rubbish pit and might have been affected by chemical solutions draining from the bottom of the pit.

QUESTIONS

A Explain clearly the errors committed by Mr Xcentric in his investigation. What were they due to, and how could they have been avoided?

B Write a brief account (or prepare a short lecture) on the history of the occupation of the site as Mr Yse might have described it.

C Explain the broken sickle found at ①.

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Unit 11

(General Revision Unit)

THE ROLE OF CHANCE IN SCIENTIFIC DISCOVERY

Nearly a century and a half ago, a Danish physicist, Oersted, was demonstrating current electricity to a class, using a copper wire which was joined to a Voltaic cell. Amongst the miscellaneous apparatus on his demonstration bench there happened to be a magnetic needle, and Oersted noticed that when the hand holding the wire moved near the needle, the latter was occasionally deflected. He immediately investigated the phenomenon systematically and found that the strongest deflection (deviation) occurred when he held the wire horizontally and parallel to the needle. With a quick jump of imagination[1] he then disconnected the ends of the wire and reconnected them to the opposite poles of the cell—thus reversing the current—and found that the needle was deflected in the opposite direction. This chance discovery of the relationship between electricity and magnetism not only led quickly to the invention of the electric dynamo and hence to the large-scale utilization of electric energy, but forms the basis for modern electro-magnetic field theory, which is now an extremely valuable tool in both macro- and micro-physics.

The above story illustrates the part played in scientific discovery by chance (accident). Again, about 20 years ago a group of British bacteriologists and biochemists working in agricultural research were carrying out investigations into substances of organic origin which could be used to stimulate plant growth. One of the approaches they used consisted in studying the nodules (small round lumps) found on the root-hairs of certain plants, and which contain colonies of nitrogen-forming bacteria. Working on the hypothesis that these bacteria manufactured a substance which stimulated the nodule-forming tissue, the investigators eventually succeeded in isolating this substance. However, when they then tested it on various other plants, they found—quite contrary (opposite) to their expectations—that it actually prevented (inhibited) growth. Further systematic investigation showed that this toxic (poisonous) effect was selective, being much greater against dicotyledon[1] plants, which happen to include the majority of weeds, than against the monocotyledons[2], which include the grain crops and grasses. The researchers thus realized that they had discovered a powerful selective weed-killer: they continued their research, using inorganic compounds of related chemical composition, and in this way laid the foundations of a technology which is of the greatest value in present-day agriculture.

Another well-known instance of the role of chance is connected with the discovery of penicillin by Fleming. This medical researcher had been investigating some pathogenic (disease-causing) bacteria, and after being absent from his laboratory for

[1] Or *intuition*, as it is often called when it produces successful results.
[2] Usually *dicots* and *monocots* respectively in U.S.A.

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some days found on his return that one of the culture dishes in which colonies of the bacteria were growing had been contaminated by a colony of another organism, a mould of penicillium *spp*. He was going to throw the dish away when he noticed that the penicillium colony was surrounded by an area completely clear of the pathogenic bacteria. He immediately realized that the penicillium must have manufactured a substance which had broken down (disintegrated) the pathogenes. He then isolated this substance, which turned out to be the most powerful agent yet discovered against bacteria causing a number of dangerous and widely-spread diseases.[1]

Apart from demonstrating the way in which chance may lead to scientific discoveries of primary importance, an analysis of the three cases outlined above may be useful in showing *how* a successful worker utilizes these accidental opportunities. The first point to notice is that although in all cases the key phenomenon produced results which were both unexpected and—in the last two cases—even apparently disadvantageous, the scientists invariably reacted in an extremely positive manner. The refusal to be disturbed or disorganized by unexpected or apparently adverse occurrences, but, on the contrary, to be stimulated by them, has in fact been a marked (strong) characteristic of successful investigators.

Secondly, we note that in the first and third cases the phenomena were very slight and might easily have escaped notice, whilst in the second case they produced a negative result. From this we might deduce that a superior capacity for observation is also a property of outstanding researchers. On this point, however, a psychologist would probably tend to disagree. He would point out that observation or perception is a concept which refers not so much to acuteness of sight, hearing, etc., or to the care with which they are applied, as to the ability to relate phenomena to a complex network of previous experiences and theories, i.e. to a meaningful frame of reference. In other words, an observer who lacks such a frame of reference will be unable to realize the significance of certain phenomena even though his senses may 'experience' them, and so he may fail to observe them. This can be illustrated by the following example:

At the end of last century, an American chemist, Hillebrand, was using a recently-developed instrument, the spectroscope, to analyse the gas given off by a certain mineral when treated with acid. This instrument works on the principle that each individual substance emits a characteristic spectrum of light when its molecules are caused to vibrate by the application of heat, electricity, etc; and after studying the spectrum which he had obtained on this occasion, Hillebrand reported the gas to be nitrogen. At this same time, another scientist, Rayleigh, happened to be investigating the anomalous fact that nitrogen obtained from the air appeared to be heavier than that obtained from other sources, e.g. ammonia (NH_3). Rayleigh repeated Hillebrand's experiment, and, immediately noticing that the spectrum showed several bright lines which were additional to those typical of nitrogen, went on to discover the rare gases argon (A) and helium (He). Why had Rayleigh observed these extra lines whereas (while) Hillebrand apparently had not? Part of the answer seems to be that the former already possessed a frame of reference which included the possibility that a different sort of N might exist; he was therefore extremely sensitive to any apparent anomaly in the behaviour of this element. Hillebrand lacked this concept, and was therefore unable to *see* the slight deviant reaction of the gas he assumed he was dealing with.

This dual (double) quality of being sensitive to, and curious about, small accidental occurrences, and of possessing a frame of reference capable of suggesting their true significance, is probably what Pasteur meant when he said 'Chance benefits only the prepared mind.' Nevertheless, it is clear (plain, obvious) that these qualities alone, even when joined to those mentioned previously, are not necessarily sufficient to ensure success: an indispensable factor in all the discoveries quoted above was careful and systematic experimentation. We may therefore conclude that it is the capacity to plan and undertake such experimentation which finally allows the investigator to make the most of his luck—if it comes.

Comprehension

1 What was the accidental phenomenon which Oersted noticed and investigated?

2 How did he make the needle deviate to the *opposite* direction to that of its original deflection?

3 What forms the basis of modern field theory?

4 What substance did the British agricultural researchers succeed in isolating?

5 Why were its effects on dicots of great interest to the investigators?

6 What are pathogenes?

7 What evidence did Fleming find which led him to assume that the penicillium broke down the pathogenes?

8 Besides illustrating the role of accident in scientific investigation, what else can we learn from the cases quoted?

(Imp) 9 Describe a strong characteristic of successful researchers which is demonstrated in each of the examples given.

10 What deduction regarding researchers might a psychologist disagree with?

(Imp) 11 Describe the concept of *observing*.

12 What is a spectroscope?

13 Why was Rayleigh interested in nitrogen?

14 What phenomena led him to discover the inert gases argon and helium?

(Imp) 15 What did Pasteur probably mean by *the prepared mind*?

(Imp.) 16 What additional capacity is usually necessary for the successful exploitation of accidental occurrences?

17 Give words meaning approximately the same as: to disintegrate; opposite; chance; marked; imagination; to inhibit; plain; deviation; whereas.

intuition clear defect check

Word Study

WORD-BUILDING

The prefix *dis*—. This is attached to words, mainly verbs and their derived adjectives and nouns, to give a negative or opposite meaning, e.g.: *dis*connect (l. 10) the opposite of *to connect*; *dis*-organized (l. 65), meaning *not organized*, etc.

EXERCISE (a)

Add the prefix *dis*- to form opposites of the following:
(nouns): ability; advantage; appearance; order; use. disability (disuse)
(verbs): agree; like; prove; integrate.
(adjective): similar. disprove

(b)

Fill in the blanks in the following with appropriate words formed in Exercise (a) above:

1 When one thing is different from another, the two things are said to be ....

2 In many cases, economic instability may lead to political and social ....

3 Hillebrand's assumption regarding the nature of the gas he had studied was ...ed by Rayleigh's investigations.

4 It is well known that atrophy, i.e. the wasting away of certain mental and physical characteristics, is caused mainly by ....

5 When an integrated organism or system breaks down or is split up into its separate parts, it is said to ....

STRUCTURAL WORDS—MODIFYING CONNECTIVES

However (l. 30), *thus* (l. 37), *when* (l. 49), *apart from* (l. 57), etc., are examples of a very important class of words with a dual function, i.e. to connect the different parts of a statement and at the same time to modify its total meaning in some way. These should now be revised by reference to Part II of the Basic Dictionary (2. Modifying Connectives).

EXERCISE

Read the following passage carefully, making sure you know the meaning of the modifying connectives (in italics), and complete the alternatives in brackets:

Although (though, in spite of the fact that) many complex problems will face the human race in the future, it is reasonable to assume that the application of the techniques of present-day science will in time (eventually) provide the solution to most of them.

To take (consider) only one of these problems—that of under-nourishment—it can reasonably be predicted that one of its main causes, i.e. over-population, will eventually be solved by the widespread use of devices for controlling human fertility, *provided that* (s------ t- the proviso that) social customs and laws are relaxed sufficiently to allow this. At present this solution is *clearly* (o-------) limited *because of* (o---- t-, b- a---- o-) these social considerations.

Another way of approaching the problem is to increase the food supplies available: this, *also* (t--), can be done through (by means of) the scientific methods we have at our disposal now, e.g. by raising the yield of crops and animals. This is possible by the introduction of genetically improved varieties and by the use of fertilizers and weed-killers, *besides* (a- w--- a-) by the extension of more scientific methods of cultivation. *Moreover* (f---------), *inasmuch as* (i- s- f- a-) these measures do not usually involve interference with existing religious or social patterns, they are more likely to be put into immediate operation than the method mentioned previously, viz. birth-control.

Notwithstanding (i- s----- o-, reg------- o-, ir------- o-) what has been stated above, however, it may be doubted whether the measures referred to will be sufficient to prevent the situation from deteriorating (becoming worse)—in the near future, at least—unless some totally new factor appears. *Nevertheless* (h------, b--), some writers consider that it is fairly probable that such factors will *indeed* (i- f---) emerge, in view of the exponential growth of science, including the social sciences. *Otherwise* (i- n--), the outlook for the human race will indeed be dark.

REVISION—COMPOUND NOUNS AND NOUN PHRASES

In Unit 6 we studied the compound noun structure and its uses. There are a number of examples of these in the Reading Passage of the present unit, e.g. *copper wire* (l. 2), *demonstration bench* (l. 4), etc. Pick these out and explain what each one means.

Structure Study Revision

TENSES

EXERCISE (a)

Put the verbs in brackets into the correct tense, either Simple Present or Simple Past (note that some irregular verbs are included):

1 People sometimes (confuse) cause and effect.

2 In the case recorded in Unit 9, the young sociologist (draw) the wrong conclusion from his data.

3 People generally (keep) oil in large storage tanks.

4 Fleming (see) that the penicillium colony was surrounded by a clear space.

5 The hotter a substance (become), the faster the movement of the molecules.

6 Torricelli (put forward—i.e. develop) a theory of air pressure over 300 years ago.

7 People (apply) scientific knowledge to practically all fields of human activity, nowadays.

8 This recently-developed instrument is Japanese: they (make) it in Japan.

9 The faster an aircraft (fly), the greater the stress and strain on the materials.

10 We generally (use) the exponential notation when we (write) down numbers in scientific work.

(b) Some of the sentences in the exercise above would more usually be put in the Passive. Find these, and put them into the corresponding Passive form.

-ing FORMS

EXERCISE

Replace the expressions in italics with an appropriate *-ing* form in each case:

1 The force *that links* atoms together to form molecules is called the chemical bond.

2 Technologists are concerned in *the application of* pure science to practical affairs.

3 Air-speeds *that exceed* several times the speed of sound have been reached by modern types of aircraft in level flight.

4 A good investigator is interested in *the explanation of* the phenomena around him.

5 Engineers in many parts of the world are engaged in *the development of* machines capable of exerting extreme pressures on materials.

6 Celestial bodies, i.e. bodies in space *that revolve* round (around) larger bodies are called satellites.

7 New electronic devices are available nowadays to help the scientist in *the computation of* complex calculations.

8 The blood *that circulates* in our veins and arteries is a mixture of several substances.

9 A type of radiation *which consists* of light and sub-atomic particles is released by radioactive elements.

10 The efficiency of a power supply system can be calculated by *a measurement of* the difference between the potential intake (input) of energy and the actual output.

-ing FORMS AND THE INFINITIVE

EXERCISE

Put the verbs in brackets into either the Infinitive or the *-ing* form, as necessary:

1 A good scientist enjoys (solve) problems.

2 Polar species of plants or animals seldom get used to (live) in warmer climatic zones.

3 Industrialization enables countries (raise) their standards of living, but it is also necessary (improve) methods of agriculture as well. *to raise* *to improve*

4 An outstanding politician is not likely (succeed) in science. (Do you agree? Is the converse necessarily true?) *to succeed*

5 We ought (write) clearly when (record) our observations. *to write* *recording*

6 It is very difficult for a single scientist (cover) all the aspects of even one discipline. *to cover*

7 In order to establish a series of wide and fertile frames of reference, a scientist should (develop) an interest in other disciplines beside his own. *develop*

8 Before (publish) his results, the wise investigator always asks other scientists (work) in the same field (check) their accuracy. *publishing* *working* *to check*

To Begin with 9 (Begin with), a young scientist often tends (overlook) the importance of (plan) his work carefully before (begin) it. *to overlook* *planning* *beginning*

~~*To take*~~ *Taking* 10 (Take) correct measurements, it is necessary (use) accurately-adjusted instruments. *to use*

IMPERSONAL EXPRESSIONS

EXERCISE

Repeat the following sentences aloud, putting the verb *be* in the correct tense (Present, Past, Future, Present Perfect):

1 Rayleigh (be) interested in Hillebrand's experiment because it (be) plain to him that the latter had used a new source to obtain nitrogen from. He thereupon decided that it (be) necessary for him to investigate the N obtained from this source. *was* *was* *was*

2 During the next decade or so, it (be) difficult to provide enough food for the rapidly-increasing world population. *will be*

3 After we had completed a series of crucial experiments last week it (be) clear that our original hypothesis was incorrect (wrong). *was*

4 Up to the present it (be) impossible to provide accurate long-term weather forecasts, though it (be) likely that a combination of meteorological satellites and computers will enable us to do so in the future. *is*

5 Many people think that it (be) obvious that a greater proportion of the resources available should be allocated to basic research. *is*

Discussion and Criticism

1 Describe in an orderly and accurate way an instrument or piece of apparatus which is used in the science you are studying. Then prepare clear and detailed instructions for its use, employing diagrams where necessary.

2 Do you agree with the remarks about *observation* given in ll. 74–83? If so, how do you think a scientist can acquire the 'wide frames of reference' required?

3 Analysing the cases outlined in the reading passage, do you think they illustrate other qualities necessary for successful investigation, apart from those mentioned in the text?

4 Describe any examples known to you which illustrate Pasteur's saying that 'Chance favours only the prepared mind'.

5 Re-read ll. 84–99. From the data given, can you form any hypothesis to explain why Rayleigh had found atmospheric nitrogen to be apparently heavier than N from other sources? How would you proceed to test this hypothesis?

6 In l. 17 there is a reference to *electro-magnetic field theory*, a specialized concept belonging to physics; l. 44 refers to *pathogenic bacteria*, a concept peculiar to medicine or bacteriology. Choose a similar specialized concept from the discipline you yourself are studying, and explain it so that a non-scientist (layman) could understand it.

BIBLIOGRAPHY

The books listed in the Bibliography to Unit 8 contain much interesting material on this subject, also:

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