Science in Classics
经典中的科学

Henri Poincaré (庞加莱)

Science and Method

What kind of beauty did Carson sense?

Nature is beautiful

Henri Poincaré (1852-1912)

The scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful.

Science and Method

What does he mean?

Core Question

What guides the scientist's mind?

The text

- *Science and Method*
- Chapters 1 and 3

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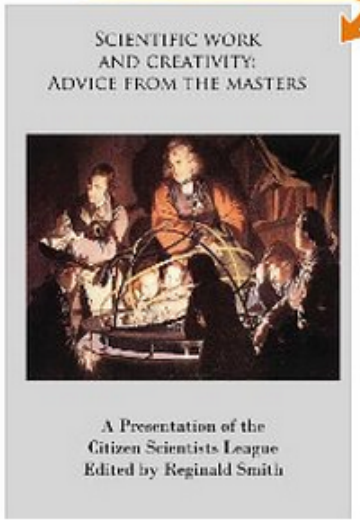

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Citizen Scientists League (Author), Reginald D. Smith (Editor)

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SCIENTIFIC WORK AND CREATIVITY: ADVICE FROM THE MASTERS

A Presentation of the
Citizen Scientists League
Edited by Reginald Smith

Science and Method

- I. The Scientist and Science
  - I. The selection of facts
  - II. The future of mathematics
  - III. Mathematical discovery
  - IV. Chance
- II. Mathematical Reasoning
  - I. The Relativity of Space
  - II. Mathematical definitions and education
  - III. Mathematics and Logic
  - IV. The new logics
  - V. The last effort of the logisticians

- III. The New Mechanics
  - I. Mechanics and radium
  - II. Mechanics and optics
  - III. The new mechanics and astronomy
- IV. Astronomical Science
  - I. The Milky Way and the theory of gases
  - II. French geodesy

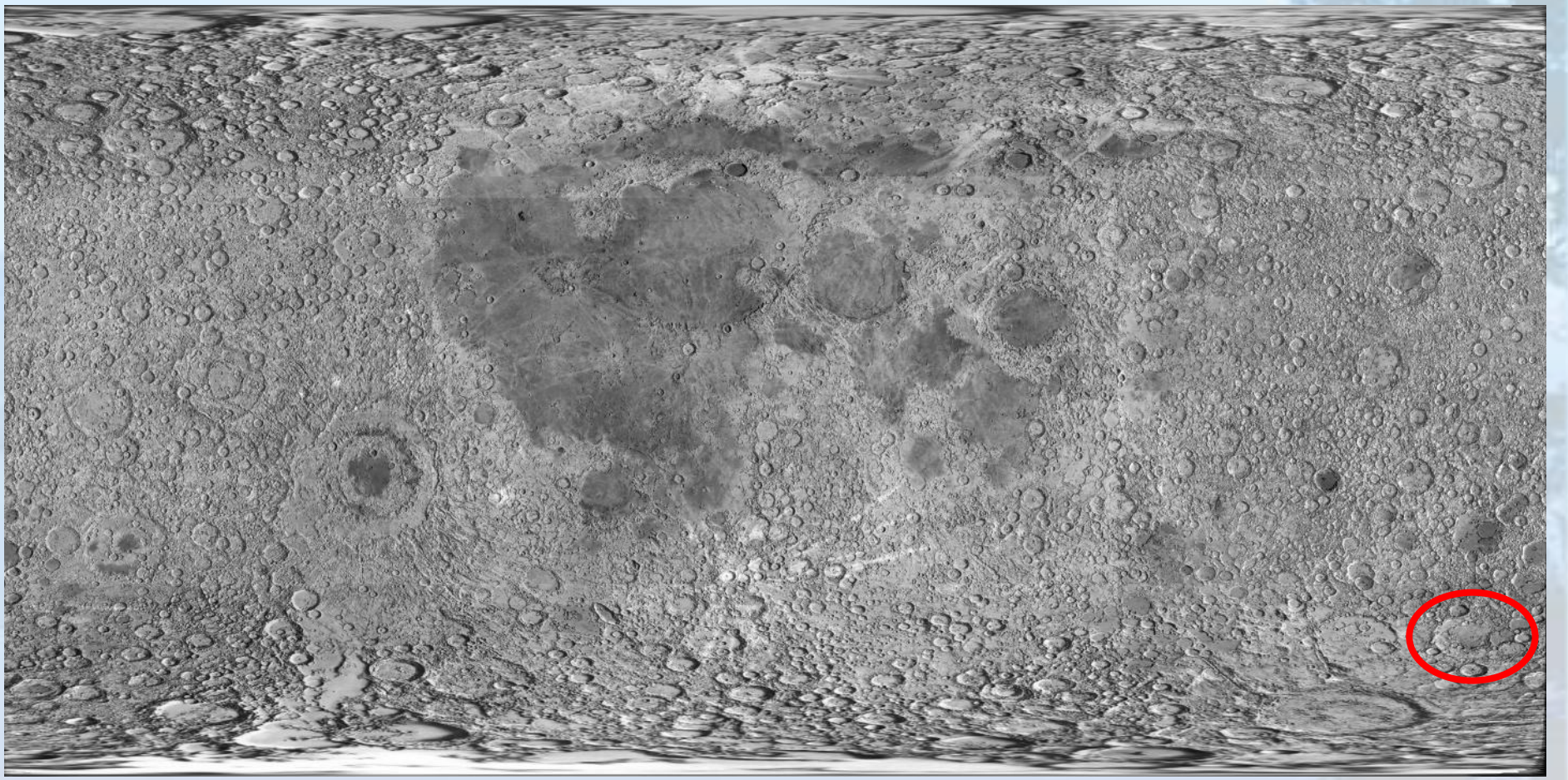
Who is Poincaré?

- Foundational work on relativity, chaos (浑沌), celestial mechanics, topology (拓朴学), 3-body problem, theory of analytic functions (解析函数) of several complex variables (复变数).

Henri Poincaré (1852-1912)

Young Poincaré

- the only member elected to every one of the five sections of the French Academy of Sciences, namely the geometry, mechanics, physics, geography and navigation sections.



Crater Poincaré

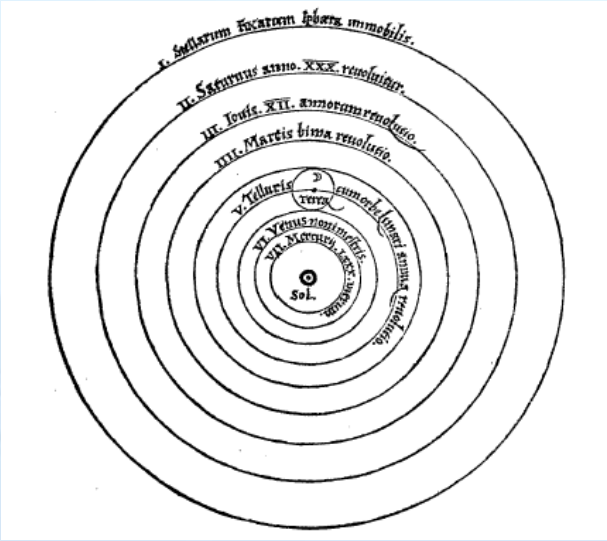
Important writings

- *Science and Hypothesis* (1902)
- *The Value of Science* (1905)
- *Science and Method* (1908)
- *Last Essays* (1913); edited by a friend one year after he died.

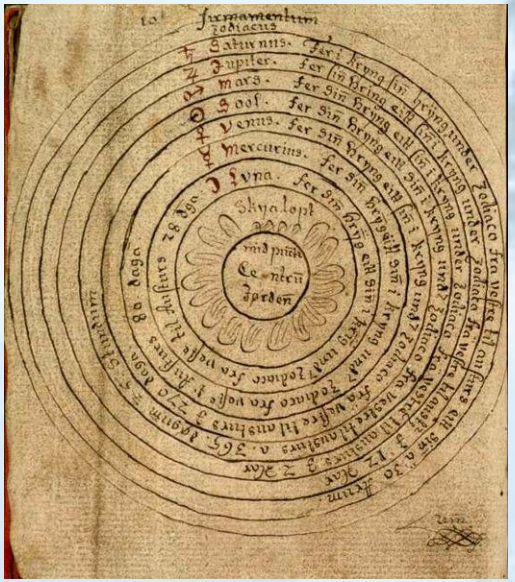
Chaos

- Poincaré found that the solar system is not stable.
- Chaos: (simply put) irregular and non-repeatable motions.
- Often found in astronomical systems and weather systems.

Stability not guaranteed



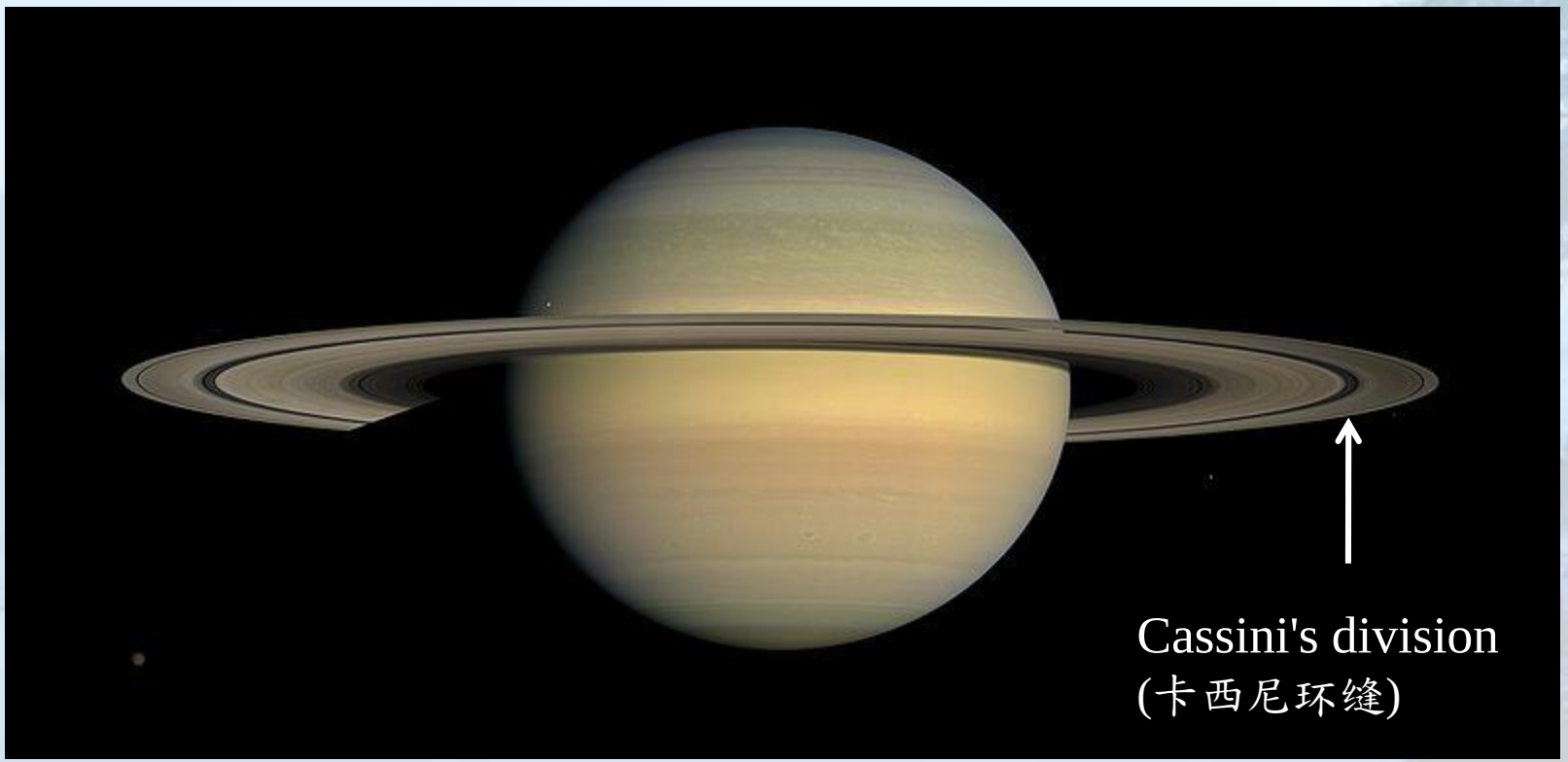
Heliocentric model



Geocentric model

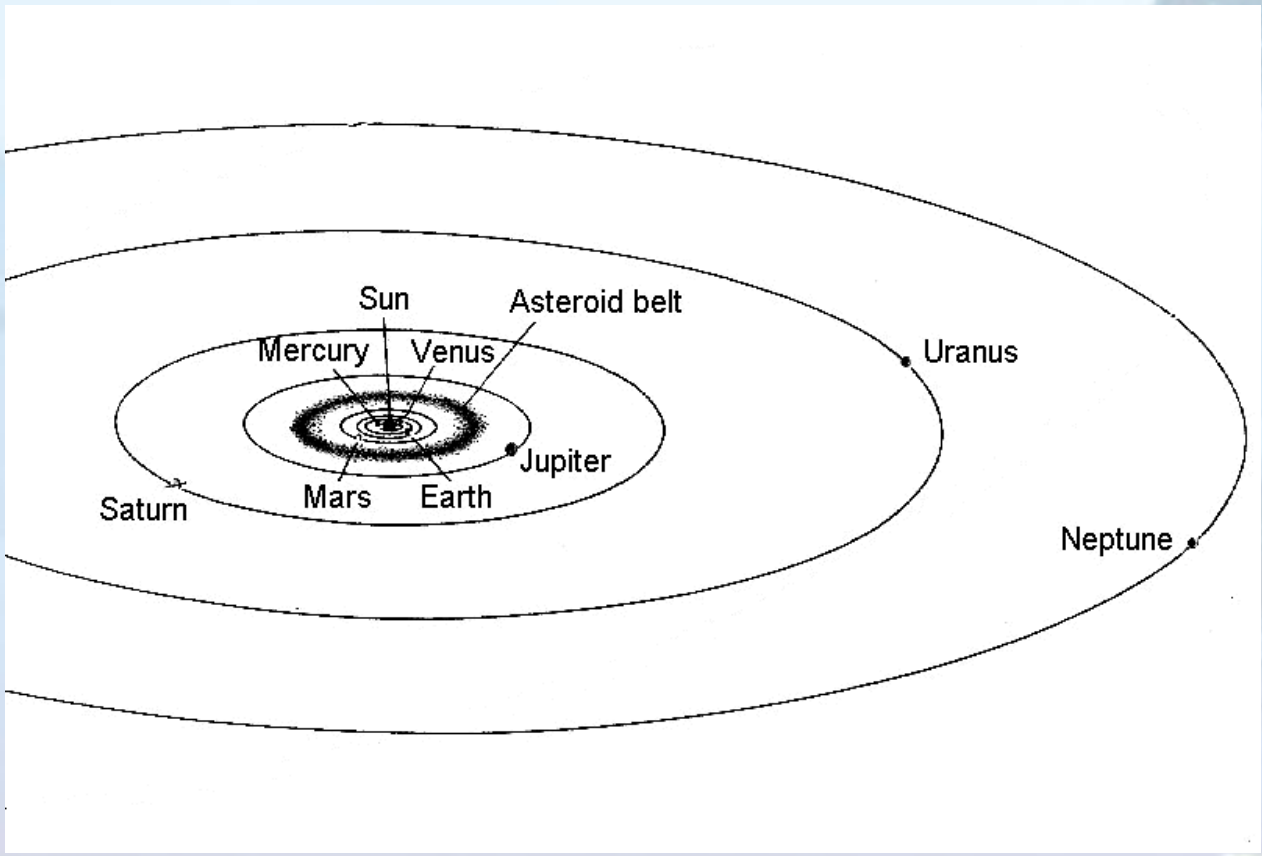
- Both heliocentric and geocentric models deem celestial motions as stable and predictable.
- But chaos put an end to stability.

Chaos everywhere!

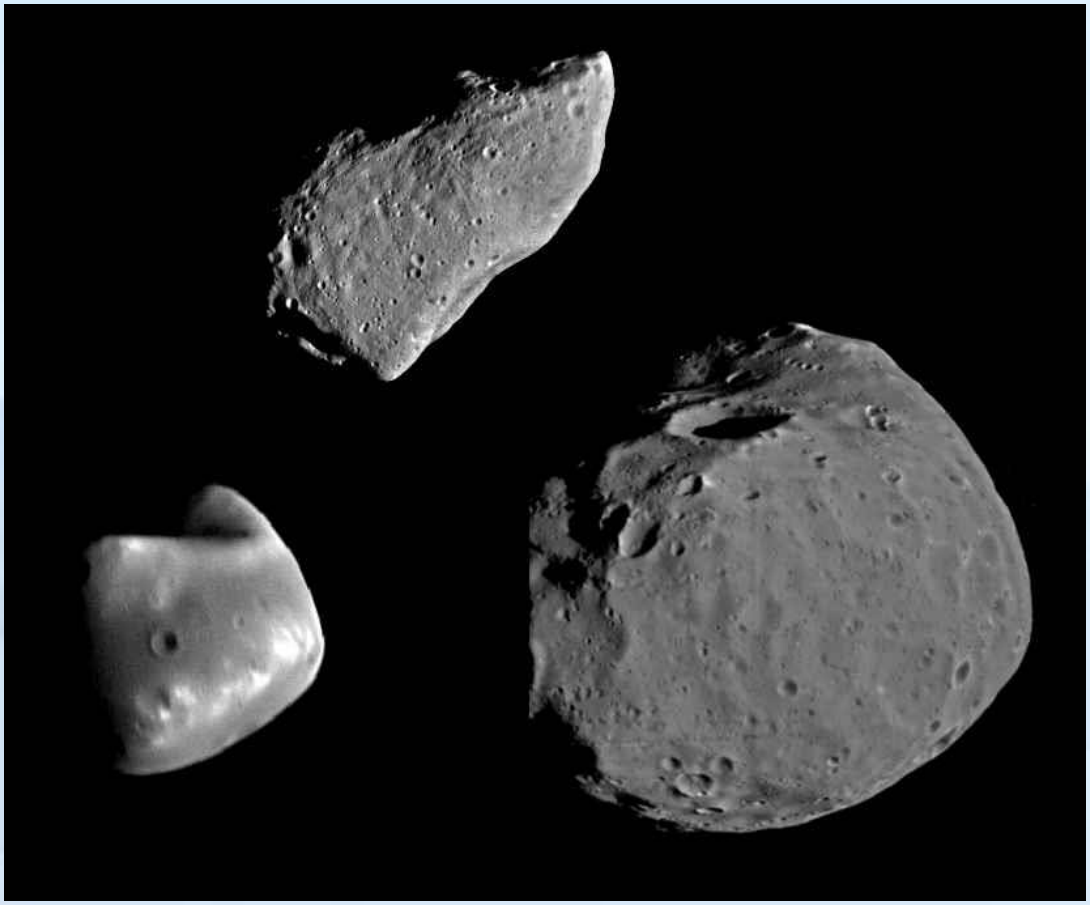


- The gaps in Saturn’s Ring are due to chaos.

The moons of Mars



The Solar System



Gaspra (Top)
Deimos (Bottom left) and
Phobos (Bottom right): The moons of Mars

- Hypothesis: the moons were asteroids undergoing chaotic motion, they were captured by Mars after leaving the asteroid belt.

A theory of extinction of dinosaurs

A large asteroid or comet undergoing chaotic motion hit the earth 65 million years ago … then …


DON DAVIS

Dust of explosion shrouded our planet for years, extinguishing Sun's ray ➔ plants died ➔ food chain disrupted ➔ dinosaurs died

Chapter I

The Selection of Facts

[Para. 1-14: What are scientists doing?]

[Para. 15-17: Why are they doing this?]

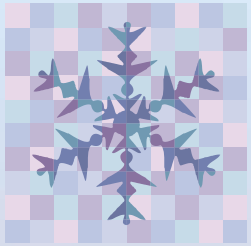
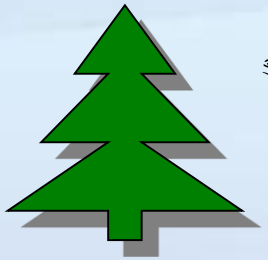
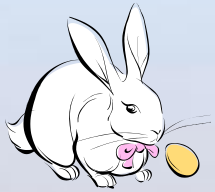
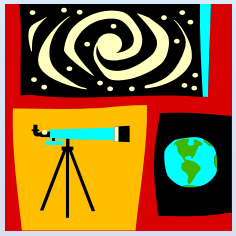
[Para. 18-21: Why is the useful also practical?]

Q1. What are scientists doing?

- There are numerous things in the world …
- What should we study? ALL of them?






I. THE SELECTION OF FACTS

Tolstoi explains somewhere in his writings why, in his opinion, "Science for Science's sake" is an absurd conception. We cannot know all the facts, since they are practically infinite in number. We must make a selection; and that being so, can this selection be governed by the mere caprice of our curiosity? Is it not better to be guided by utility, by our practical, and more especially our moral, necessities? Have we not some better occupation than counting the number of lady-birds in existence on this planet? 1

Line of thought (Para. 1-14)

1. Selection must be made (Para. 1) [Select what?]
2. Select recurring facts (Para. 6-7) [Which are recurring facts?]
3. Simple facts (Para. 8) [Where can simple facts be found?]
4. Infinitely large and small (Para.10)
5. Result: Economy of thought (Para. 14)

6 What these fools did, as Mach has said, was to save their successors the trouble of thinking. If they had worked solely in view of an immediate application, they would have left nothing behind them, and in face of a new requirement, all would have had to be done again. Now the majority of men do not like thinking, and this is perhaps a good thing, since instinct guides them, and very often better than reason would guide a pure intelligence, at least whenever they are pursuing an end that is immediate and always the same. But instinct is routine, and if it were not fertilized by thought, it would advance no further with man than with the bee or the ant. It is necessary, therefore, to think for those who do not like thinking, and as they are many, each one of our thoughts must be useful in as many circumstances as possible. For this reason, the more general a law is, the greater is its value.

7 This shows us how our selection should be made. The most interesting facts are those which can be used several times, those which have a chance of recurring. We have been fortunate enough to be born in a world where there are such facts. Suppose

- Useful (有用) ≠ practical (实用), useful = correct in many circumstances
- want to find general laws (useful thoughts)
- ⇨ select recurring (再现) facts (Para. 7)

Line of thought (Para. 1-14)

1. Selection must be made (Para. 1) [Select what?]
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4. Infinitely large and small (Para.10)
5. Result: Economy of thought (Para. 14)

Which, then, are the facts that have a chance of recurring? In the first place, simple facts. It is evident that in a complex fact many circumstances are united by chance, and that only a still more improbable chance could ever so unite them again. But are there such things as simple facts? and if there are, how are we to recognize them? Who can tell that what we believe to be simple does not conceal an alarming complexity? All that we can say is that we must prefer facts which appear simple, to those in which our rude vision detects dissimilar elements. Then only two alternatives are possible; either this simplicity is real, or else the elements are so intimately mingled that they do not admit of being distinguished. In the first case we have a chance of meeting the same simple fact again, either in all its purity, or itself entering as an element into some complex whole. In the second case the intimate mixture has similarly a greater chance of being reproduced than

8

First kind

Second kind

- Which are recurring facts? Ans: Simple facts.
- Two kinds of simplicity:
  - Real simplicity.
  - Simplicity resulted from thorough mixing.

Line of thought (Para. 1-14)

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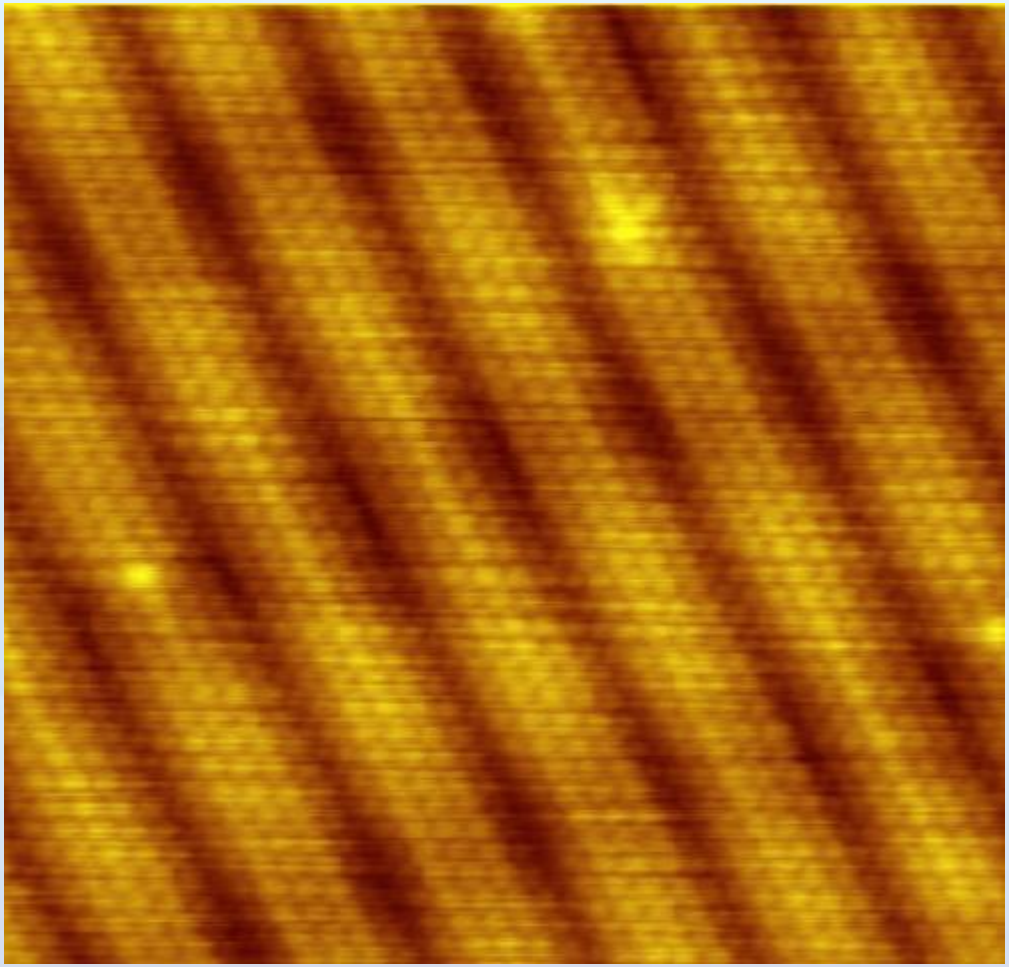
2. Select recurring facts (Para. 6-7) [Which are recurring facts?]
3. Simple facts (Para. 8) [Where can simple facts be found?]
4. Infinitely large and small (Para.10)
5. Result: Economy of thought (Para. 14)

But where is the simple fact? Scientists have tried to find it in the two extremes, in the infinitely great and in the infinitely small. The astronomer has found it because the distances of the stars are immense, so great that each of them appears only as a point and qualitative differences disappear, and because a point is simpler than a body which has shape and qualities. The physicist, on the other hand, has sought the elementary phenomenon in an imaginary division of bodies into

- Where to find simple facts?
  - Ans: In the infinitely great
  - Ans: In the infinitely small


Hubble Ultra Deep Field
The infinitely great

Gold atoms as seen under a scanning tunneling microscope



The infinitely small

(*Wikimedia Commons*)

Line of thought (Para. 1-14)

1. Selection must be made (Para. 1) [Select what?]
2. Select recurring facts (Para. 6-7) [Which are recurring facts?]
3. Simple facts (Para. 8) [Where can simple facts be found?]
4. Infinitely large and small (Para.10)
5. Result: Economy of thought (Para. 14)

I cannot dwell further on this point, but these few words will suffice to show 14
that the scientist does not make a random selection of the facts to be observed. He does not count lady-birds, as Tolstoi says, because the number of these insects, interesting as they are, is subject to capricious variations. He tries to condense a great deal of experience and a great deal of thought into a small volume, and that is why a little book on physics contains so many past experiments, and a thousand times as many possible ones, whose results are known in advance.

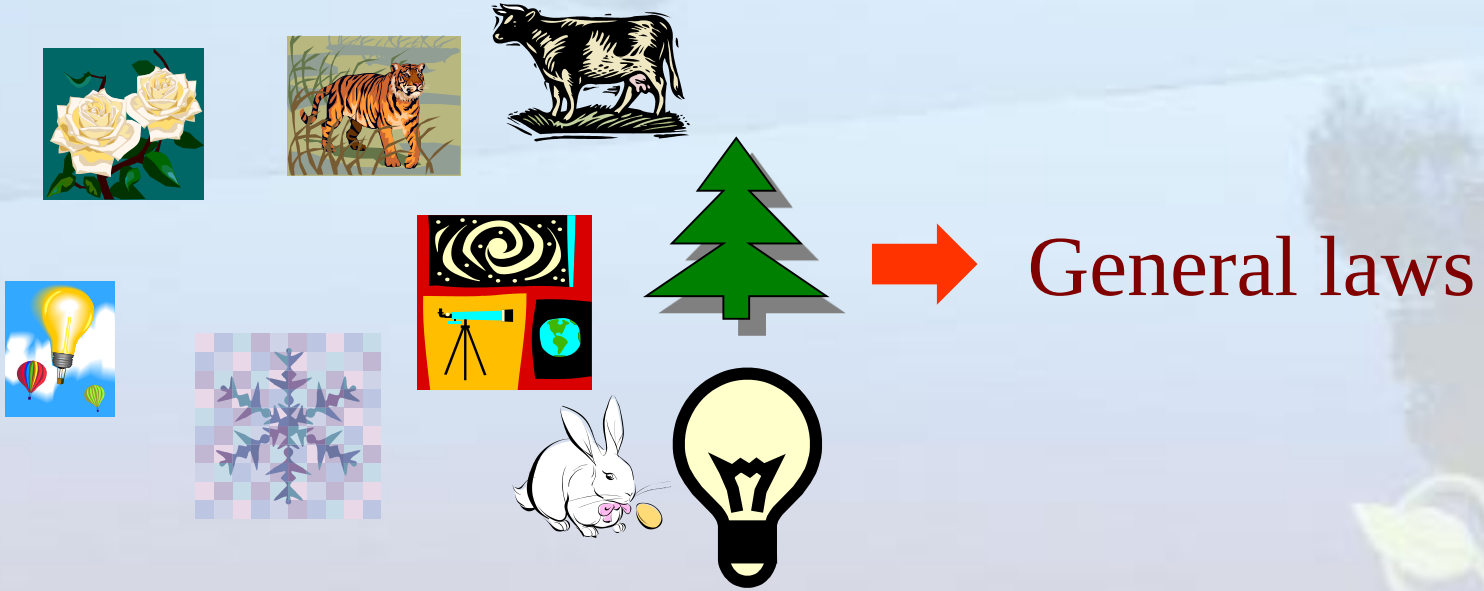
- General laws ⇨ economy of thoughts

Line of thought (Para. 1-14)

1. Selection must be made (Para. 1) [Select what?]
2. Select recurring facts (Para. 6-7) [Which are recurring facts?]
3. Simple facts (Para. 8) [Where can simple facts be found?]
4. Infinitely large and small (Para.10)
5. Result: Economy of thought (Para. 14)

Q2. Why are they doing this?

- What is the driving force?
- Where does the satisfaction come from?



The driving force

But so far we have only considered one side of the question. The scientist 15
does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful. If nature were not beautiful it would not be worth knowing, and life would not be worth living. I am not speaking, of course, of that beauty which strikes the senses, of the beauty of

- satisfaction of the sense of beauty (Para. 15)

Line of thought (Para. 15-17)

1. The sense of beauty (Para. 15) [What is beauty?]
2. Beauty = harmony (Para. 16); the sense of harmony makes us select the facts that contribute to this harmony. [Why do simple facts (Para. 1-14) contribute to the harmony?]
3. Because simple facts are beautiful. (Para. 17)

- Comment: He has not answered the question.
  - Why do simple and vast facts contribute to the harmony?

16 It is, then, the search for this special beauty, the sense of the harmony of the world, that makes us select the facts best suited to contribute to this harmony; just as the artist selects those features of his sitter which complete the portrait and give it character and life. And there is no fear that this instinctive and unacknowledged preoccupation will divert the scientist from the search for truth. We may dream of a harmonious world, but how far it will fall short of the real world! The Greeks, the greatest artists that ever were, constructed a heaven for themselves; how poor a thing it is beside the heaven as we know it!

- the beauty = the harmony
- The sense of harmony makes us select the suitable facts.

Line of thought (Para. 15-17)

1. The sense of beauty (Para. 15) [What is beauty?]
2. Beauty = harmony (Para. 16); the sense of harmony makes us select the facts that contribute to this harmony. [Why do simple facts (Para. 1-14) contribute to the harmony?]
3. Because simple facts are beautiful. (Para. 17)

- Comment: He has not answered the question.
  - Why do simple and vast facts contribute to the harmony?

(simplicity in the infinitely large)

17 It is because simplicity and vastness are both beautiful that we seek by preference simple facts and vast facts; that we take delight, now in following the giant courses of the stars, now in scrutinizing with a microscope that prodigious smallness which is also a vastness, and now in seeking in geological ages the traces of a past that attracts us because of its remoteness.

- Reason: simplicity and vastness (恢宏) are beautiful.
- Result: we prefer simple facts and vast facts.

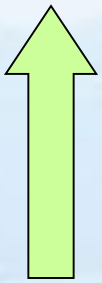
Line of thought (Para. 15-17)

1. The sense of beauty (Para. 15) [What is beauty?]
2. Beauty = harmony (Para. 16); the sense of harmony makes us select the facts that contribute to this harmony. [How do simple facts (Para. 1-14) contribute to the harmony?]
3. Because simple facts are beautiful. (Para. 17)

- Comment: He has not answered the question.
  - How do simple and vast facts contribute to the harmony (=beauty)?

Nature

Beautiful / Harmonious

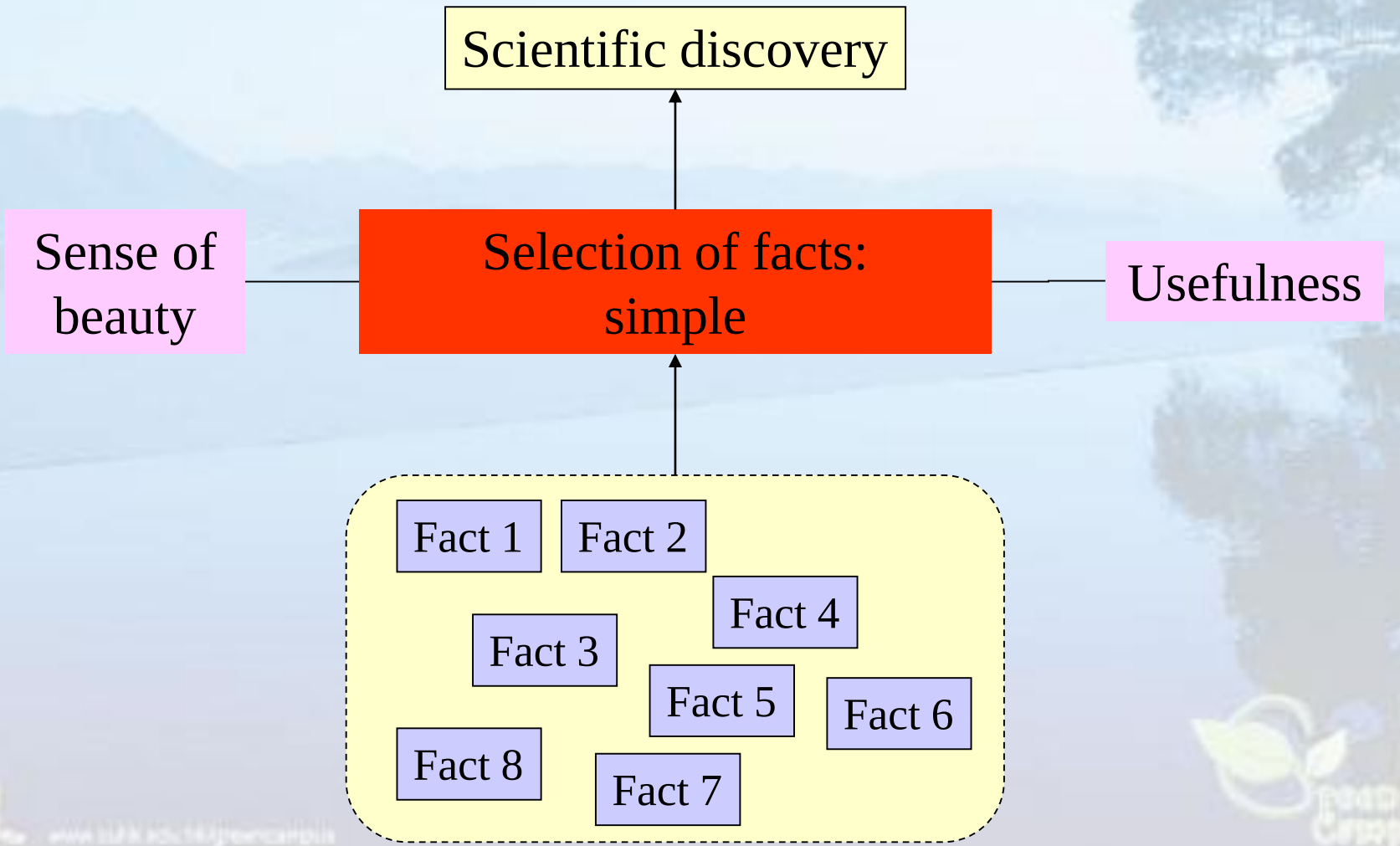


How?

Facts

Recurring = Simple

The flow


Scientific discovery
Sense of beauty
Selection of facts: simple
Usefulness
Fact 1
Fact 2
Fact 4
Fact 3
Fact 5
Fact 6
Fact 8
Fact 7

Para. 18-21

Sense of beauty ➡ Usefulness

Sense of beauty ? Practical advantage

Change our life, defeat enemies …

18 Thus we see that care for the beautiful leads us to the same selection as care for the useful. Similarly economy of thought, that economy of effort which, according to Mach, is the constant tendency of science, is a source of beauty as well as a practical advantage. The buildings we admire are those in which the architect has succeeded in proportioning the means to the end, in which the columns seem to carry the burdens imposed on them lightly and without effort, like the graceful caryatids of the Erechtheum.

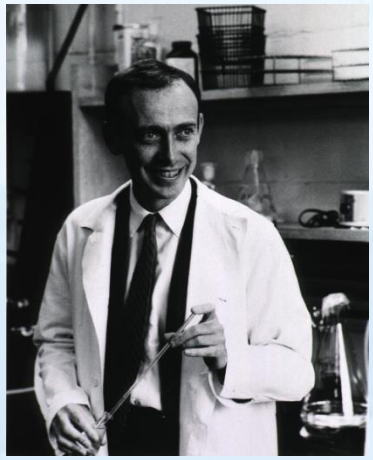
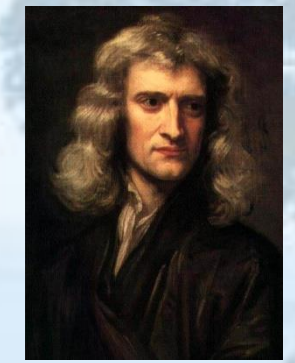
19 Whence comes this concordance? Is it merely that things which seem to us beautiful are those which are best adapted to our intelligence, and that consequently they are at the same time the tools that intelligence knows best how to handle? Or is it due rather to evolution and natural selection? Have the peoples whose ideal

Chapter III

Mathematical Discovery

They are geniuses!!!!



- How did their brains work?

Chapter III

- Why did Poincaré choose mathematical discovery to discuss?

III. MATHEMATICAL DISCOVERY

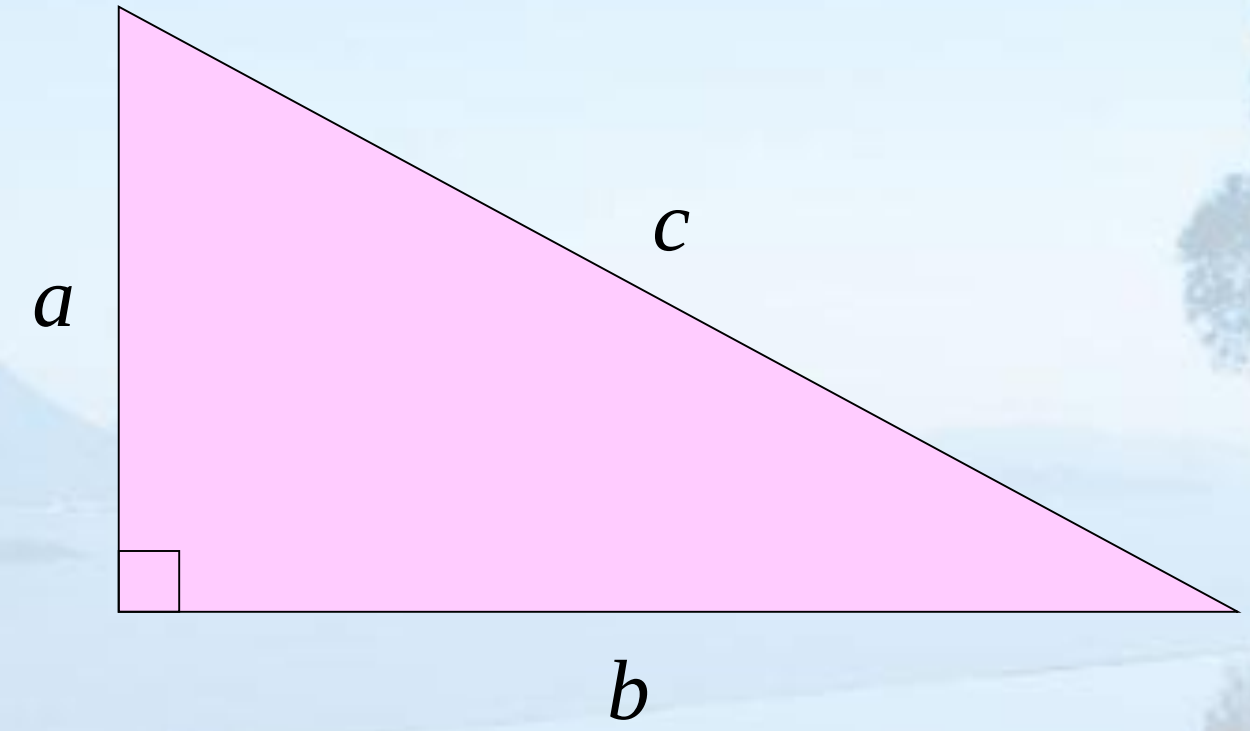
The genesis of mathematical discovery is a problem which must inspire the psychologist with the keenest interest. For this is the process in which the human mind seems to borrow least from the exterior world, in which it acts, or appears to act, only by itself and on itself, so that by studying the process of geometric thought we may hope to arrive at what is most essential in the human mind. 1

Plato would be happy with this.

What is discovery?

- Para. 2-12: A good memory does not necessarily lead to discovery.
- Para. 13-17: What is mathematical discovery?

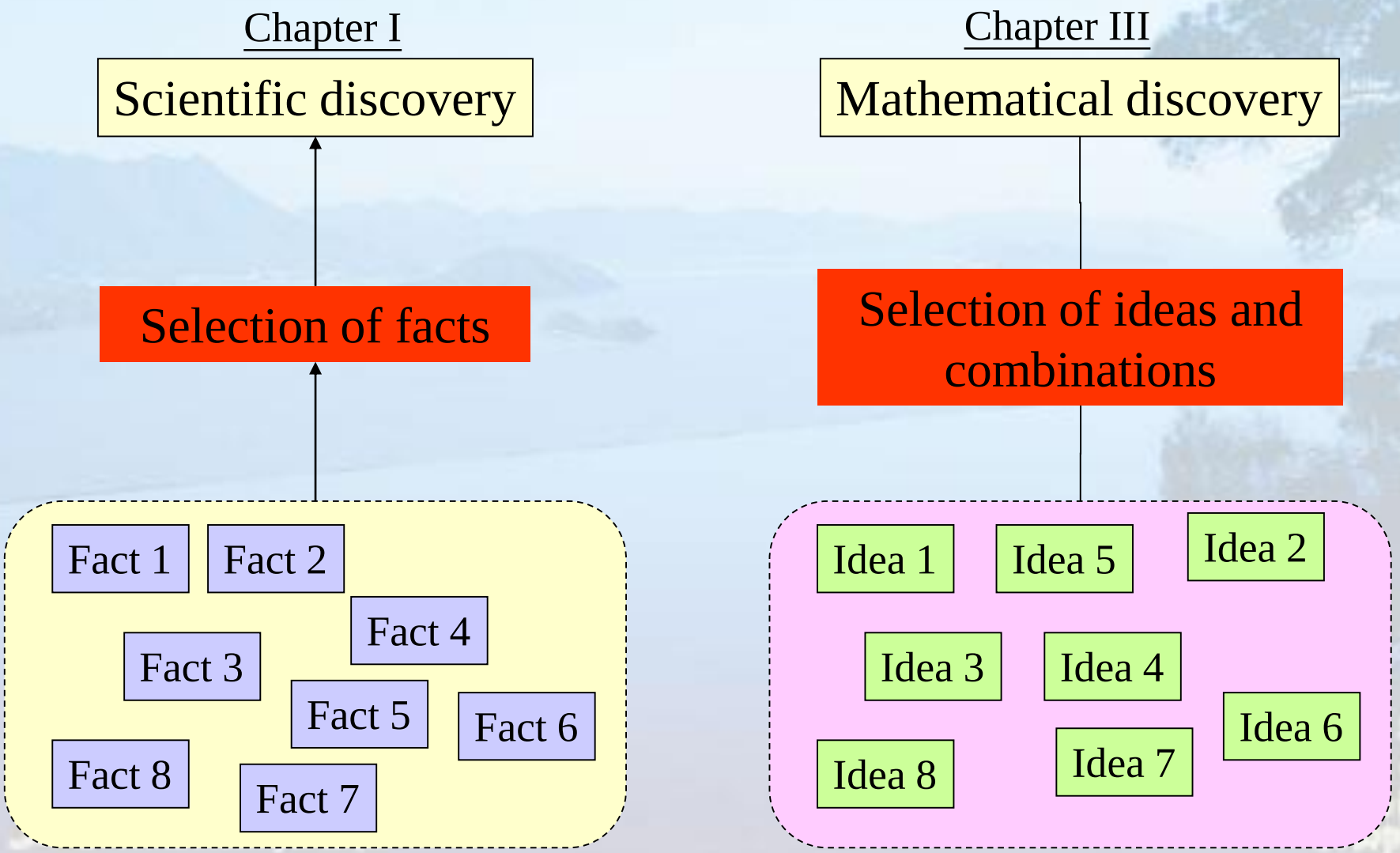
13 What, in fact, is mathematical discovery? It does not consist in making new combinations with mathematical entities that are already known. That can be done by anyone, and the combinations that could be so formed would be infinite in number, and the greater part of them would be absolutely devoid of interest. Discovery consists precisely in not constructing useless combinations, but in constructing those that are useful, which are an infinitely small minority. Discovery is discernment, selection.



The three sides can be combined in this way:

$$c^2 = a^2 + b^2$$

A parallel between the two chapters



What guides the selection?

- Intuition.

order, and the order in which these elements are placed is much more important than the elements themselves. If I have the feeling, so to speak the intuition, of this order, so that I can perceive the whole of the argument at a glance, I need no longer be afraid of forgetting one of the elements; each of them will place itself naturally in the position prepared for it, without my having to make any effort of memory.

It seems to me, then, as I repeat an argument I have learnt, that I could have 11
discovered it. This is often only an illusion; but even then, even if I am not clever enough to create for myself, I rediscover it myself as I repeat it.

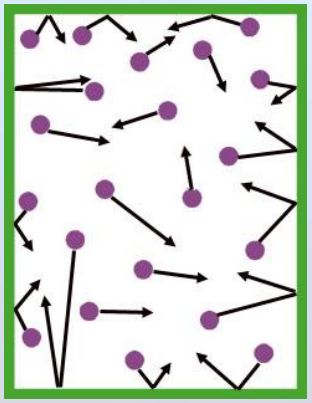
We can understand that this feeling, this intuition of mathematical order, 12
which enables us to guess hidden harmonies and relations, cannot belong to everyone. Some have neither this delicate feeling that is difficult to define, nor a power of memory and attention above the common, and so they are absolutely

It is time to penetrate further, and to see what happens in the very soul of the mathematician. For this purpose I think I cannot do better than recount my personal recollections. Only I am going to confine myself to relating how I wrote my first treatise on Fuchsian functions. I must apologize, for I am going to introduce some

18

Para. 18-38: Main theme

[Para. 39-47: A pictorial description of the main theme]



Ideas = atoms
They form combinations.

Psychology of mathematical discovery

- Beside the conscious ego, we have also a subliminal ego.
- Three steps in mathematical discovery
  1. Conscious work (fruitless)
  2. Unconscious work (with a sense of beauty)
  3. Conscious work (verification)

There is another remark to be made regarding the conditions of this unconscious work, which is, that it is not possible, or in any case not fruitful, unless it is first preceded and then followed by a period of conscious work. These sudden inspirations are never produced (and this is sufficiently proved already by the examples I have quoted) except after some days of voluntary efforts which appeared absolutely fruitless, in which one thought one had accomplished nothing, and seemed to be on a totally wrong track. These efforts, however, were not as barren as one thought; they set the unconscious machine in motion, and without them it would not have worked at all, and would not have produced anything.

Do you want some coffee?

For a fortnight I had been attempting to prove that there could not be any 19
function analogous to what I have since called Fuchsian functions. I was at that
time very ignorant. Every day I sat down at my table and spent an hour or two
trying a great number of combinations, and I arrived at no result. One night I took
some black coffee, contrary to my custom, and was unable to sleep. A host of ideas
kept surging in my head; I could almost feel them jostling one another, until two of

46 I will make one last remark. When I related above some personal observations,
I spoke of a night of excitement, on which I worked as though in spite of myself. The
cases of this are frequent, and it is not necessary that the abnormal cerebral activity
should be caused by a physical stimulant, as in the case quoted. Well, it appears
that, in these cases, we are ourselves assisting at our own unconscious work, which
becomes partly perceptible to the overexcited consciousness, but does not on that

Beauty again

34

It may appear surprising that sensibility should be introduced in connexion with mathematical demonstrations, which, it would seem, can only interest the intellect. But not if we bear in mind the feeling of mathematical beauty, of the harmony of numbers and forms and of geometric elegance. It is a real aesthetic feeling that all true mathematicians recognize, and this is truly sensibility.

35

Now, what are the mathematical entities to which we attribute this character of beauty and elegance, which are capable of developing in us a kind of aesthetic emotion? Those whose elements are harmoniously arranged so that the mind can, without effort, take in the whole without neglecting the details. This harmony is at once a satisfaction to our aesthetic requirements, and an assistance to the mind which it supports and guides. At the same time, by setting before our eyes a well-ordered whole, it gives us a presentiment of a mathematical law. Now, as I have said above, the only mathematical facts worthy of retaining our attention and capable of being useful are those which can make us acquainted with a mathematical law. Accordingly we arrive at the following conclusion. The useful combinations are precisely the most beautiful, I mean those that can most charm that special sensibility that all mathematicians know, but of which laymen are so ignorant that they are often tempted to smile at it.

Criteria for selections?

- The sense of beauty.
- Then what is beauty?
- Any limitations of scientific and mathematical discoveries?

I am going to tell you.

Final advice

Don’t be absorbed in sidetracks

I. THE SELECTION OF FACTS

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Businessmen

Tolstoi

It is clear that for him the word *utility* has not the meaning assigned to it by 2
business men, and, after them, by the greater number of our contemporaries. He cares but little for the industrial applications of science, for the marvels of electricity or of automobilism, which he regards rather as hindrances to moral progress. For him the useful is exclusively what is capable of making men better.

(Chapter I)

- These people are practical.

5 But scientists believe that there is a hierarchy of facts, and that a judicious selection can be made. They are right, for otherwise there would be no science, and science does exist. One has only to open one's eyes to see that the triumphs of industry, which have enriched so many practical men, would never have seen the light if only these practical men had existed, and if they had not been preceded by disinterested fools who died poor, who never thought of the useful, and yet had a guide that was not their own caprice.

6 What these fools did, as Mach has said, was to save their successors the trouble of thinking. If they had worked solely in view of an immediate application, they would have left nothing behind them, and in face of a new requirement, all

(Chapter I)

- Businessmen are enriched by industry.
- Scientists (fools) thought for them but died poor.

Skip the technical terms

It is time to penetrate further, and to see what happens in the very soul of the 18
mathematician. For this purpose I think I cannot do better than recount my personal recollections. Only I am going to confine myself to relating how I wrote my first treatise on Fuchsian functions. I must apologize, for I am going to introduce some technical expressions, but they need not alarm the reader, for he has no need to understand them. I shall say, for instance, that I found the demonstration of such and such a theorem under such and such circumstances; the theorem will have a barbarous name that many will not know, but that is of no importance. What is interesting for the psychologist is not the theorem but the circumstances.

For a fortnight I had been attempting to prove that there could not be any 19
function analogous to what I have since called Fuchsian functions. I was at that time very ignorant. Every day I sat down at my table and spent an hour or two trying a great number of combinations, and I arrived at no result. One night I took some black coffee, contrary to my custom, and was unable to sleep. A host of ideas kept surging in my head; I could almost feel them jostling one another, until two of them coalesced, so to speak, to form a stable combination. When morning came, I had established the existence of one class of Fuchsian functions, those that are derived from the hyper-geometric series. I had only to verify the results, which only took a few hours.

(Chapter III)

More background is needed

No doubt Tolstoi would be horrified at such a triumph, and he would refuse 20
to admit that it could be truly useful. But this disinterested pursuit of truth for its own beauty is also wholesome, and can make men better. I know very well there are disappointments, that the thinker does not always find the serenity he should, and even that some scientists have thoroughly bad tempers.

Must we therefore say that science should be abandoned, and morality alone 21
be studied? Does anyone suppose that moralists themselves are entirely above reproach when they have come down from the pulpit? (Chapter I)

- Why talk about scientists with bad tempers?
- Why talk about moralists?
- More background is needed.

Universal suffrage (?)

This has long been understood, and a few months ago a review called 2
L'Enseignement mathématique, edited by MM. Laisant and Fehr, instituted an enquiry into the habits of mind and methods of work of different mathematicians. I had outlined the principal features of this article when the results of the enquiry were published, so that I have hardly been able to make any use of them, and I will content myself with saying that the majority of the evidence confirms my conclusions. I do not say there is unanimity, for on an appeal to universal suffrage we cannot hope to obtain unanimity.

(Chapter III)

- Another sidetrack.

Annotation

文本 5 (Poincaré) 注释

这篇文本的难处有二：1. 作者从抽象的角度看科学，缺乏例子；2. 有很多看来与主题无关的枝节，尽显作者个人风格。其实注释还未完成，而且是初版，希望各位指正。

I. Selection of Facts

Para. 1–3: 这三段稍嫌离题。第一段回应题旨，先指出事实无穷 (infinite)，故必须选择，随即提出两个选择的原则：(i) 纯粹兴致 (caprice)（有 short-term desire 之意）；(ii) 功利 (utility)。在第二段，他讨论托尔斯泰（Tolstoi，第一段首个名字）对功利的看法，指出托尔斯泰所理解的功利不是商家 (businessmen) 所理解的工业应用 (industrial applications)，而是使人变得更好 (making men better) 的意思。就在我们以为作者会在托尔斯泰和商家两种看法之中选取一种的时候，他竟说：I could not be satisfied with either of these ideals。他指两种看法其实就像富豪统治 (plutocracy) 和民主 (democracy)，选择哪一种都只是品味问题 (a matter of taste)。

Para. 4–5: "Nonetheless the question remains"（然而，问题仍在）表示作者返回正题。首先他说：「如果选择只是由兴致 (caprice) 或即时需要 (immediate necessity) 来决定，则不再有为科学而科学，结果就是没有科学。他问「这是真的吗？」(Is this true?) 这看来不是反问，而且答案是 yes。（若是反问，答案就是 no 了。）因此，作者在第 5 段首提出了兴致和即时需一要之外的第三个可能：a hierarchy of facts（事实的层次）。

End