Complementarity and the Fall of Strict Causality

(Talk 3)

- What's the point of having a mind if you can't change it?

- My mind is made up; don't confuse me with facts.

Gron Tudor Jones

Let Heisenberg set the scene for the C20th (QM)

The Renaissance

* … during this period a new authority appeared which was completely independent of Christian religion or the philosophy of the Church, the authority of experience, of the empirical fact …

* Galileo did not only *think* about mechanical motions, the pendulum and the falling stone: he performed experiments to find out, quantitatively, how these motions took place …

* This new activity was in its beginning certainly not meant as a deviation from the Christian religion. On the contrary, one spoke of 2 kinds of revelation of God. The one was written in the Bible and the other was to be found in the book of nature.

* The Holy Scripture had been written by man and was therefore subject to error, while nature was the immediate expression of God's intentions.

The changing aspect of reality

* In the Middle Ages what we now call the symbolic meaning of a thing was in some way its primary reality.

* The emerging concept of reality changed towards what we can perceive with our senses … this new concept of reality is connected with a new activity: we can experiment and see how things really are.

The Controversy

The representatives of:

* **natural science** could argue that experience offers indisputable truth, that it cannot be left to any human authority to decide about what really happens in nature, and that this decision is made by nature or in this sense, God. (Nature being God's creation.)

* **traditional religion** could argue that by paying too much attention to the material world, to what we perceive with our senses, we lose connection with the essential values of human life, with just that part of reality which is beyond the material world.

These arguments do not meet, and therefore, the problem could not the resolved by any kind of agreements or decision.

Classical science and mental attitudes that stem from it

* Science: the world consists of matter in space and time; matter can produce forces, and can be acted upon by forces to move causally.
(Laplace: give me initial data on all particles and I will predict the future of the universe.)

* By the 19th century, human attitudes towards nature became less contemplative, and more pragmatic and utilitarian, leading to a spectacular growth of technical science – our mastery of the material world.

* This deterministic outlook prevailed outside science too. The trend everywhere was to believe our experiences, our senses (not the same as experiments).

* This very narrow and rigid mental frame had very little room for concepts such as the human soul, the meaning of life. They became less relevant and gradually, the hostility between science and religion grew.

* Confidence in the scientific method, and in rational thinking seemed to be replacing all other safeguards of the human mind.

Modern physics … the most important change brought about by its results consists in the dissolution of this rigid frame of concepts of the 19th century.

Physics and Philosophy (Ch 11), Heisenberg

Human creativity

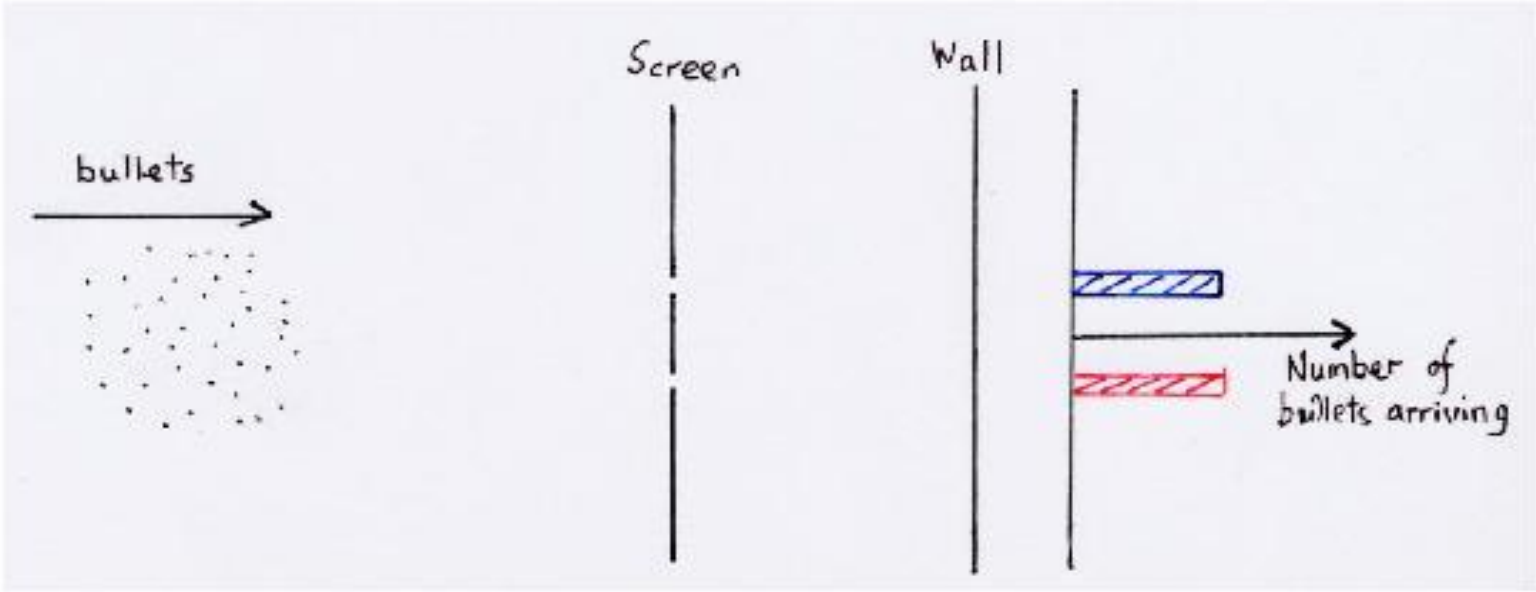
- creation myths and religious systems
- philosophies
- art and literature
- music
- science and technology
- medicine
- social structures

Weisskopf: … these attempts to give meaning to life may seem ‘ … to be incommensurable, mutually exclusive, or even contradictory; I believe a better word is *complementary* … they represent different aspects of reality, one aspect excluding the other, yet each adding to our understanding of the phenomenon as a whole.’

Introduction to complementarity

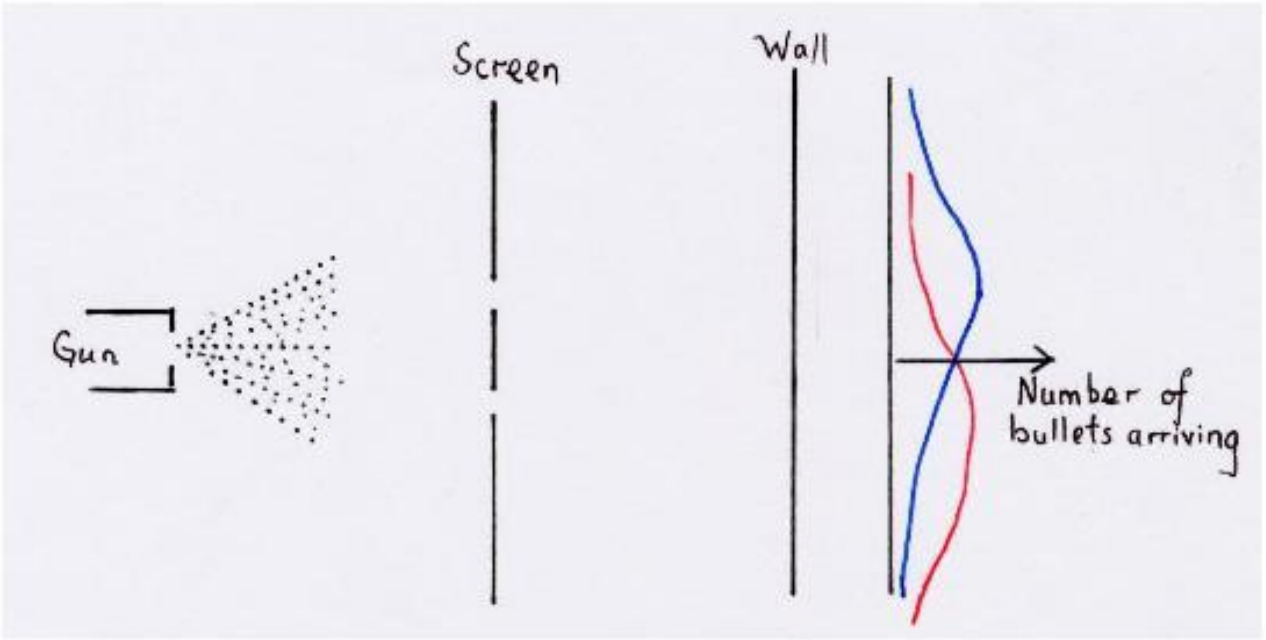
Will see how the authority of experiment persuaded physicists to give up a cherished principle, 'strict causality', a cornerstone of the Enlightenment, to make the leap forward that has most extended mankind's understanding of the workings of nature – **quantum mechanics**.

The 2-slit experiment with classical particles

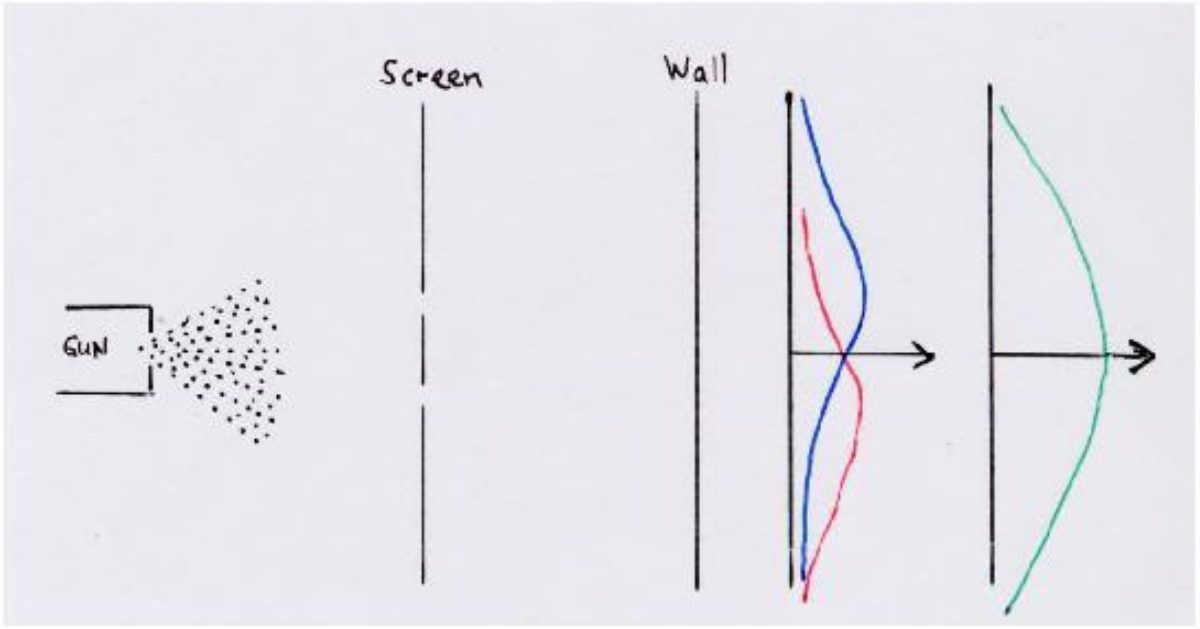


Idealised case – pile-up behind slits

More ‘realistic’ – from *The Feynman Lectures*:



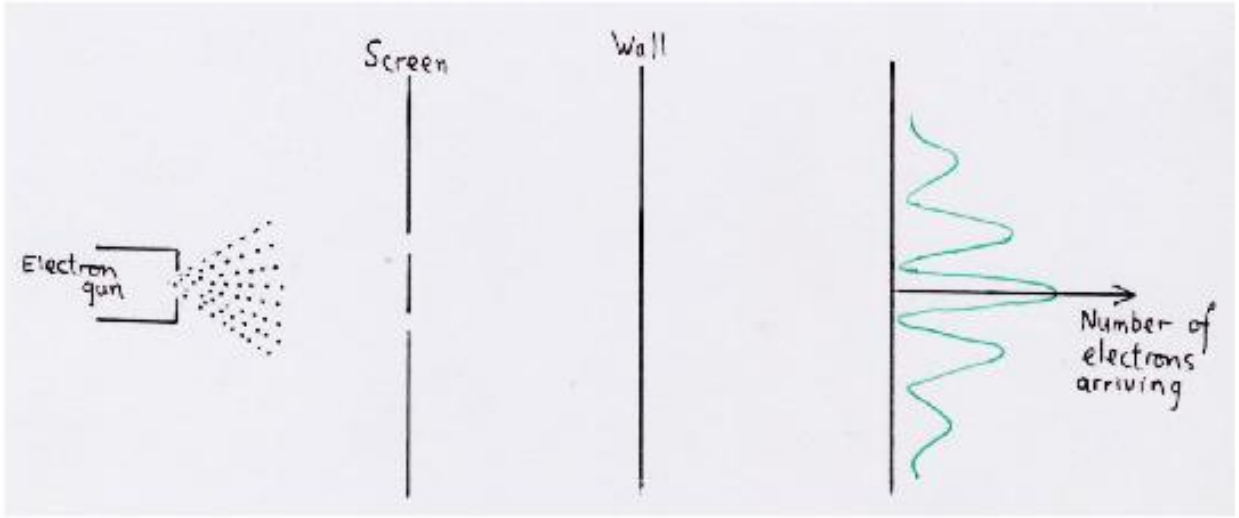
Two smeared-out bumps with peaks behind slits



Green curve is the sum of the red and blue curves.

This is what a Newtonian physicist would expect.

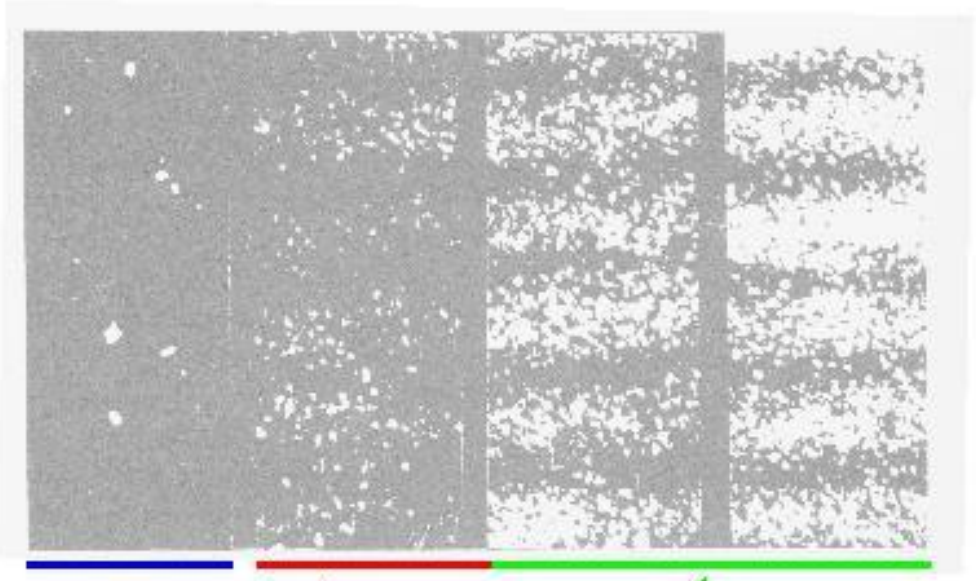
The 2-slit experiment with electrons



- Nothing like green curve of previous slide (Newtonian)!

- Describe what is found.

More on the 2-slit experiment with electrons



Longer exposures - showing pattern ever more clearly.

~10 seconds - begin to see suggestion of the high-count-then-low-count pattern.

~$\frac{1}{4}$ second - sparsely-populated pattern of spots corresponding to electron hits; looks random.

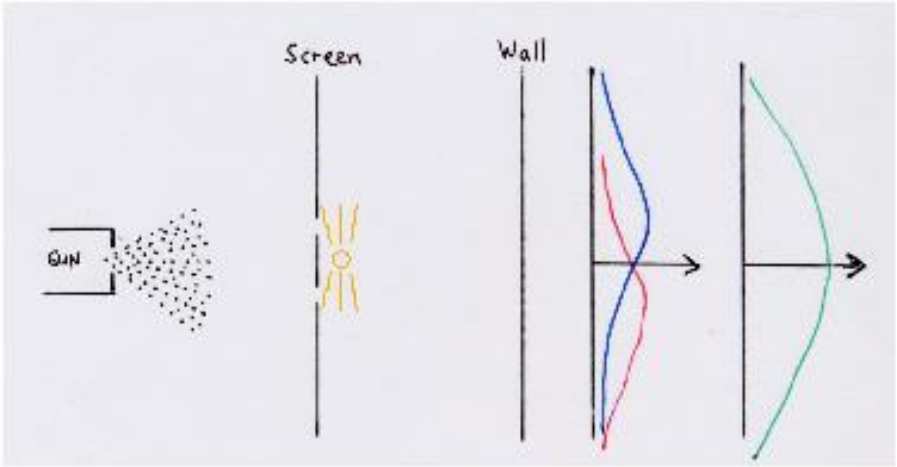
Conclusion

One could conclude then, that although we detect the electrons one-by-one as localised particles, the fact that we have a characteristic 2-slit 'interference pattern' of arrival destinations on the wall shows that, in some sense, each electron must have passed through both slits.

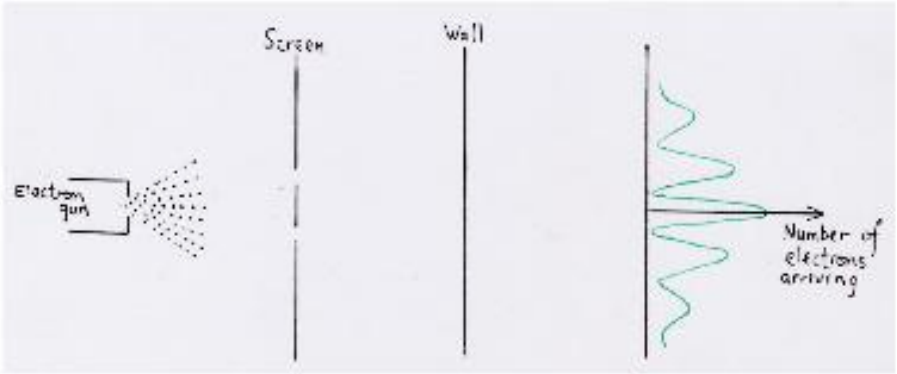
Next question in Feynman's discussion:

Can we do an experiment to see which slit an electron goes through?

Yes: electrons are charged and scatter light … put light source near the slits … look for a 'flash' …



Lamp on - no interference pattern



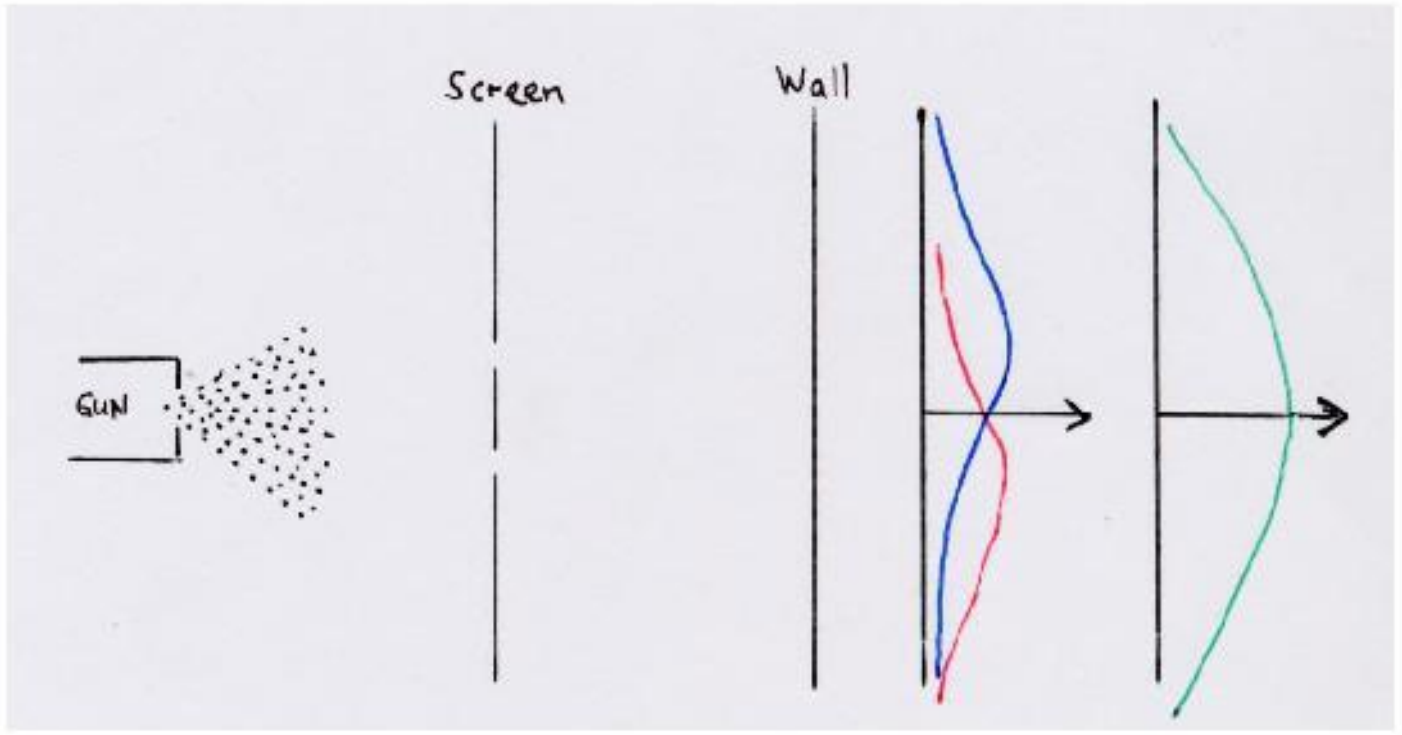
Lamp off - interference pattern returns

Describe carefully.

* To every ‘hit’ on wall … see flash near one slit … never both.

So: <u>when we check</u>, find e^- goes thru one slit or the other.

* Keep track of where these electrons end up and plot their arrival points:



* NOTE: there is no interference pattern, as there was when we didn't look.

* Switch **off** the lamp … interference pattern returns.

* What is happening?

  Photon hitting e^- disturbs it enough to destroy the interference pattern.
  No way round this … a fundamental property of nature.

* On atomic scale – what we find out about nature depends what 'question' we ask!
  - One experiment: e^- is a wave
  - Another experiment: e^- is a particle

* 2 mutually exclusive aspects of the nature of the e^- which, taken together, 'add to our understanding of the phenomenon as a whole'.

Known as **'wave-particle complementarity'**

* Discussion/questions

Weisskopf: We cannot at the same time experience the artistic content of a Beethoven sonata and also worry about the neurophysiological processes in our brains.

The epistemological lesson of quantum theory (N Bohr)

Niels Bohr … complementarity might have value in addressing issues outside physics.

Reference: *Niels Bohr's Times, In Physics, Philosophy and Polity,* A Pais, Oxford: Clarendon Press.

Example: 'A person contemplates, is spectator, when planning his action, and again when reflecting on its results. In between, when acting, he is, one hopes, also thinking but not in contemplative mode. To be spectator is as necessary for executing and evaluating a role of actor as to perform the act itself. These two modes of engagement are both necessary elements in the person's mental content, yet they exclude each other – the are complementary.'

Victor Weisskopf on the need for complementary attitudes

* What we need is a broader sense of complementary attitudes. Scientific, ethical, artistic and religious approaches are not contradictory; the complement each other.

* Today's educational system faces an important task. It needs reform in many ways … it should include tolerance and enthusiasm for the variety of human endeavours.

This is not ethical relativism or a denial of values. On the contrary, it would derive ethical principles from many sources.

* Education on all levels, from elementary schools to colleges, should foster an attitude of openness and understanding for different complementary approaches to the realities of life.

* Such an attitude is one of the preconditions for the survival of our civilisation.

Epilogue (from Plato)

Gods vs Giants

Metaphysical idealists

Secular sceptics

Tarnas: The constant interplay of these two partly complementary and partly antithetical sets of principles established a profound inner tension within the Greek inheritance, which provided the Western mind with the intellectual basis, at once unstable and highly creative, for what was to become an extremely dynamic evolution lasting 2500 years.

Excerpt from Plato's *The Sophist*

STRANGER: … there seems to be a sort of Battle of the Gods and Giants going on … because of their dispute about existence.

THEAETATUS: How so?

STRANGER: One side drags everything from heaven and the unseen to earth, rudely grasping rocks and trees in their hands. For they get their grip on all such things and they maintain that that alone exists which can be handled and touched. They define body and existence as the same thing, and if anyone says that one of the other things which does not have body exists they completely despise him and are unwilling to listen to another word.

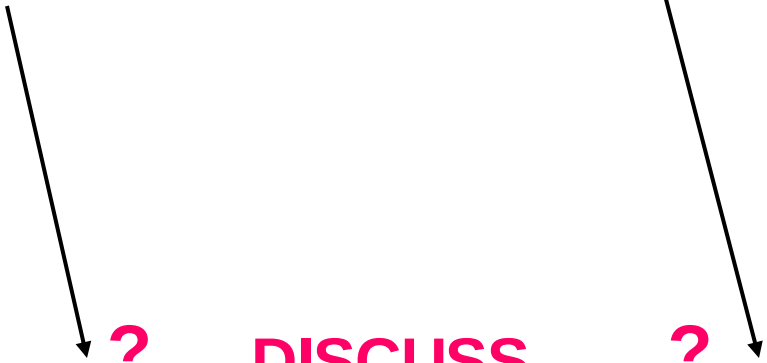
THEAETETUS: Terrible men they are of whom you speak. I have met with a lot of them in my time.

STRANGER: For that reason, those who battle against them defend themselves very carefully from somewhere above in the unseen, contending that true existence consists in certain incorporeal forms which are objects of the mind. But they pound the bodies of their opponents and what these call truths into small pieces in their arguments, denouncing it as a sort of motion or becoming. There is always, Theaetetus, an interminable battle going on between these two camps …

THEATETETUS: True.

How the **Gods** should defend themselves against the **Giants**.

Antony Flew: What they require for victory is examples of things which, while undoubtedly incorporeal, can nevertheless be shown to exist.



? DISCUSS ?

Once any incorporeal objects are admitted … extreme negative claims of Giants are defeated … and the door is ajar for admission of further incorporeals …

* Fast-forward about 2500 years!

The human consciousness – beyond science?

Neville Mott (Introduce)

Without our bodies with their molecules and the electric currents in our brains, we would not have our consciousnesses, but I put our consciousness outside physics and chemistry and above them.

Refers to famous lecture – *The Invincible Ignorance of Science* – by Brian Pippard:

He argues … not only that consciousness is not at this time understood from the laws of physics, but that it cannot be so understood.

To me then, human consciousness lies outside science …

… incorporeal? Discuss.

So what?

Pippard[1]: The consequence for the scientist is that he must remain **agnostic** about phenomena that accompany the manifestation of mind.

It is tempting for the scientist, with the assurance he commands in his own realm, to dismiss the religious experience as a delusion. To be sure, he has a right to parade the evidence that makes him sceptical of antiquated cosmologies such as religions are apt to carry in their train; and he is right to despise dogmas that imply a God whose grandeur does not match up to the grandeur of the universe he knows.

But when we have chased out the mountebanks, there remain the saints and those of transparent integrity whose confident belief is not to be dismissed simply because it is inconvenient or unshared.

[1] GOOGLE pippard ignorance zotero

We may lack the gift of belief ourselves, just as we may be tone-deaf; but it is becoming in us to envy those whose lives are radiant with a truth which is no less true for being incommunicable. As scientists we have a craftsman's part to play in the City of God; we cannot receive the freedom of that city until we have learnt to respect the freedom of every citizen.

Is this what Heisenberg had in mind when he claimed that modern physics would dissolve the 'rigid frame of concepts of the 19th century'?

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Odds and ends …

The Hydrogen Atom

The energy of an electron confined to the vicinity of a proton by electrical attraction is given by

E = kinetic energy + potential energy

$$= \frac{p^2}{2m} - \frac{e^2}{4\pi\epsilon_0 r} \qquad \text{I}$$

The position of the electron is 'uncertain' by an amount that is roughly $\frac{r}{2}$, half the 'radius' of the atom; i.e. $\Delta r \sim \frac{r}{2}$

By the Heisenberg Uncertainty Principle, the corresponding uncertainty in momentum is

$$\Delta p \sim \frac{h}{2\pi r}$$

But the average momentum p of the electron must be zero (otherwise the electron would leave the proton!); so

$$p \sim \frac{h}{2\pi r} \qquad \text{II}$$

Substitute II into I to get

$$E = \frac{h^2}{8\pi^2 m r^2} - \frac{e^2}{4\pi\epsilon_0 r}$$

The favoured value of r is the one that minimizes the energy, which we get by putting $\frac{dE}{dr} = 0$

i.e. $$\frac{-2h^2}{8\pi^2 m} \cdot \frac{1}{r^3} + \frac{e^2}{4\pi\epsilon_0 r} = 0$$

i.e. $$r(\text{minimum energy}) = \frac{h^2\epsilon_0}{\pi e^2 m}$$

Put in the numbers: $h = 6.63 \times 10^{-34}$ J s
$\epsilon_0 = 8.85 \times 10^{-12}$ F/m
$e = 1.6 \times 10^{-19}$ C
$m = 9.11 \times 10^{-31}$ kg

$$r(\text{minimum energy}) = 0.53 \times 10^{-10} \text{ metre} \qquad \text{III}$$

Comparable to what we get from the spreading oil drop experiment!

- To get the minimum energy put III into I to get

$$E = \frac{h^2}{8\pi^2 m} \frac{\pi^2 e^4 m^2}{h^4 \epsilon_0^2} - \frac{e^2}{4\pi\epsilon_0} \frac{\pi e^2 m}{h^2 \epsilon_0}$$

$$= -\frac{1}{8} \frac{me^4}{h^2 \epsilon_0^2}$$

Substituting the numbers we get

$$E = 13.6 \text{ eV}$$

→ EXACTLY THE ENERGY NEEDED TO GET AN ELECTRON OUT OF A HYDROGEN ATOM!