



### Empiricism vs. Rationalism

Ditch your assumptions?

## 'Empirical'

 'Empirical' = pertaining to experience, observation, or experiment.

• E.g. empirical studies, empirical investigation, empirical knowledge, empirical data

• Contrasted with "theoretical" investigation, theoretical knowledge, etc.

## Empiricism

- In philosophy, empiricism is the claim that all of our knowledge comes from experience. There is no innate (inborn), or *a priori* knowledge (prior to experience).
- In the context of scientific knowledge, "empiricism" is used a little more loosely. It can just mean an emphasis on empirical rather than theoretical methods.

### Rationalism

- Rationalism, as the term is used in philosophy, is contrary to empiricism.
- Rationalism says that our minds have been made to fit the world we are in (or vice versa). Hence there is a happy agreement between the structure of our concepts and the structure of the world.
- Our intuitive feelings about how the world *ought to be* are often correct, therefore.

 Rationalists are not always theists (believers in God) but many are.

• E.g. the astronomer Johannes Kepler thought that God was a mathematician who used geometrical patterns to create the world, and then planted those same geometrical ideas in our minds. "Geometry, which before the origin of things was coeternal with the divine mind and is God himself (for what could there be in God which would not be God himself?), supplied God with patterns for the creation of the world, and passed over to Man along with the image of God; and was not in fact taken in through the eyes."

#### **Johannes Kepler**

(Harmonice Mundi, The Harmony of the World (1619), book IV, ch. 1. Trans. E. J. Aiton, A. M. Duncan and J. V. Field (1997), 304)



 In 1919, after an experiment confirmed Einstein's theory of general relativity, a reporter asked Einstein what would it have meant if his theory was wrong. He replied: "God would have missed a great opportunity"

Einstein actually didn't believe in a personal god, but in a higher being "who reveals himself in the lawful harmony of all that exists, but not in a God who concerns himself with the fate and the doings of mankind."



### This is how rationalists talk

"One has a great confidence in the theory arising from its great beauty, quite independent of its detailed successes ... One has an overpowering belief that its foundations must be correct quite independent of its agreement with observation."

Paul Dirac (physicist) 1980. (Also not a believer in God.)



 $\left(\beta mc^2 + \sum_{k=1}^{3} \alpha_k p_k c\right) \psi(\mathbf{x}, t) = i\hbar \frac{\partial \psi(\mathbf{x}, t)}{\partial t}$ 

• 'I have no better expression than the term "religious" for this trust in the rational character of reality and in its being accessible, at least to some extent, to human reason. Where this feeling is absent, science degenerates into senseless empiricism'

• Einstein, letter to Maurice Solovine



- On these rationalist views, our expectations of how the world *ought to* work have some validity.
  - While such expectations are sometimes wrong, so we shouldn't adhere to them rigidly, we should nevertheless pay attention to them.
  - This suggests that we have some innate, or a priori, knowledge. (Knowledge prior to, or independent of, experience.)

### Baconian empiricism

• Francis Bacon (1561-1626). English Lord Chancellor and philosopher. A champion of the new empirical emphasis in science. His main work is the *Novum Organon*, or "New Tool", 1620.



26. To help me get my ideas across, I have generally used different labels for human reason's two ways of approaching nature: the customary way I describe as *anticipating nature* (because it is rash and premature); and the way that draws conclusions from facts in the right way I describe as *interpreting* nature.

**36.** There remains for me only one way of getting my message across. It is a simple way, namely this: I must lead you to the particular events themselves, and to the order in which they occur; and you for your part must force yourself for a while to **lay aside your notions** and start to familiarize yourself with facts.

"lay aside your notions"

 I.e. ditch your initial assumptions, prejudices, etc. Don't think *anything* until you look and see what's really there. Come to the world with a completely open mind.

• Is that how scientists should work?

### **Sherlock Holmes**

 "It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts" 45. The human intellect is inherently apt to suppose the existence of more order and regularity in the world than it finds there. Many things in nature are unique and not like anything else; but the intellect devises for them non-existent parallels and correspondences and relatives. That is how it comes about that all the heavenly bodies are thought to move in perfect circles . . .

 Here Bacon refers to Plato, Aristotle and their followers, who held that the heavens must be perfect, and so the planets must move in perfect circles (since circles are the most perfect shape).

• How did that work out for them?

- **49.** The human intellect doesn't burn with a dry light, because what the person *wants* and *feels* gets pumped into it; and that is what gives rise to the 'please-yourself sciences'. For a man is more likely to believe something if he would like it to be true. ...
  - In short, there are countless ways in which, sometimes imperceptibly, a person's likings colour and infect his intellect.

 Again, Bacon acknowledges that scientists do not lay aside their notions, in general. In many cases "a person's likings colour and infect his intellect".

• Of course Bacon sees this as a bad thing!

95. Those who have been engaged in the sciences divide into experimenters and theorists. The experimenters, like ants, merely collect and use particular facts; the theorists, like spiders, spin webs out of their own substance. But the bee takes a middle course: it gathers its material from the flowers of the garden and the field, but uses its own powers to transform and absorb this material.

- We see that Bacon recognises the need for theory, as well as observation. The bee first collects nectar (data) from the flowers, and then processes it into honey (forms theories out of the data).
- Note however that observation comes *first*, and theory second.
- Also, theorising doesn't supply extra material, but just processes observations into a usable form.

A true worker at philosophy is like that: he doesn't rely solely or chiefly on the powers of the mind (like a theorist = spider), and he doesn't take the material that he gathers from natural history and physical experiments and store it up in his memory just as he finds it like an experimenter (= ant). Rather, he stores the material in his intellect, altered and brought under control. So there is much to **hope** for from a closer and purer collaboration between these two strands in science, experimental and theoretical - a collaboration that has never occurred before now.

## Case history: The sun's place in the universe

- The planets are now known to orbit the sun
- How did this theory come about?
- Was the theory derived from the data alone?
- If not, then did the prior notions and assumptions help, or get in the way?

### Copernicus

- Copernicus proposed that the sun lies at the centre of the universe, and the earth is a planet.
- This new model was in certain ways more elegant and intellectually pleasing than the older model of Ptolemy.
- But the empirical accuracy of Copernicus's model wasn't too good – no better than the old geocentric model.

### Why is the sun special?

 We've seen that in Ptolemy's universe the sun is a very special planet, since (apart from the moon) every other planet's orbit involves a duplication of the solar orbit.



### Copernicus's explanation

- According to Copernicus, the sun doesn't really orbit the celestial sphere, once per year.
- The sun is really stationary, and merely *appears* to move, since we observe it from a moving earth.
- Of course the earth's motion causes *every* planet to appear to move with the same annual circular motion as the sun. That's why Ptolemy's model includes all the circles shown in yellow.

## Much less ad hoc

- Why did Ptolemy put all those duplications of the solar orbit into his model ?
- Recall that these were *ad hoc* adjustments, needed to explain the following data:
  - Mercury and Venus stay close to the sun
  - Mars, Jupiter and Saturn undergo retrograde motion when in opposition.
- A heliocentric model, by contrast, *must* have these features. They are unavoidable.

### Copernicus :

"We thus follow Nature, who producing nothing in vain or superfluous often prefers to endow one cause with many effects."

De Revolutionibus, Book 1, Chapter 10

• Is it *reasonable* (or *justified*) for a scientist to accept heliocentrism on this basis?

# Why was Copernicus's model inaccurate?

- The basic problem here is that the orbits of the planets are not quite circular. They are slightly oval. And the speed of a planet around its orbit isn't quite constant.
- Ptolemy approximated the orbits using minor epicycles, eccentric orbits and equants, as we have seen.
- Copernicus had to use similar fudges, for the same basic reason.

### Ptolemy's full model of Mercury



 Just as messy! ☺

NICOLAI COPERNICI quoce epicyclum hoc modo. Sit mundo ac Soliho 11. AB, & A C B diameter, in qua fumma ablis contingat. Eta A centro epicyclus describatur D E, ac rursus in D centros r emeric um F c, in quo terra uerfetur, omniace in codem plan parte tarding read ad medium amis space exacts . I long. coming Exercisely primi to ad A - second D. ad K. ac ann re feil hoceff liter a fed in m dentia o modo O intellique rume : lincam to a or tune quando e 501 primi tpie . er @funt fint real nes . N estalmen medio tamé mi epicyclycetrum re aposeo fol uerjatur. aring r sudyas funt O centraq dentia Alestin . 5370 renty primi e fecundy. G p unde mo de hypothe finn quod cum terra fuerit in r, maximum efficiet Solis ap gogeon secondi sprinch \$ I don't by landow prime in a minimum ; in medns autem circumferentis

### Copernicus's three minor epicycles



### Kepler cleans up the mess

- Kepler accepted Copernicus's view that the sun is at the centre of the universe.
- But Kepler was unhappy with the complexity and inaccuracy of the Copernican model.
- Kepler found that each planet's orbit (apart from the moon) could be modelled very precisely by a single ellipse, with the sun at one focus.

### An ellipse's focal points





Kepler's speed law: Equal areas are swept out in equal times

### Is the ellipse messy too?

- Longomontanus (long-time assistant to the late Tycho Brahe) told Kepler that his model was a "sordid insolence". Kepler's aim to clean up the mess of the Copernican model was a total failure, so that he was still "submerged in shit in the Augean stable of old".
- Kepler replied indignantly to Longomontanus as follows:

"If you are angry that I cannot eliminate the oval path, how much more ought you to be angry with the spirals, which I abolished. It is as though I have sinned with the oval I have left, even though to you all the rest of the ancients do not sin with so many spirals. This is like being punished for leaving behind one barrow full of shit although I have cleaned the rest of the Augean stables."

- How did Kepler come up with the idea of elliptical rather than circular orbits?
- Did the *data* lead him to this?
  - (N.B. he *did* use very accurate data, obtained by his former boss, Tycho Brahe.)

• Newton said in a letter to Halley in June 1686,

"Kepler knew the Orb to be not circular but oval, and guest it to be Elliptical"

Kepler *guessed* the ellipse – he didn't mathematically derive it. (Such a derivation is absolutely impossible.) Kepler used math only to check the accuracy of his guess.

# "Conic Sections" (Mathematicians' favourite curves)



• The ellipse was the second-simplest curve known to mathematicians.

- So Kepler's solution was much more simple, mathematically elegant, etc. than the medieval theory with its ugly equants and eccentrics.
- Kepler did not "lay aside his notions", and arguably would have gotten nowhere had he done so.

Kepler's calculations to find the *best* fit (for a circle, ellipse, etc.) involved a lot of work!

"If this wearisome method has filled you with loathing, it should more properly fill you with compassion for me as I have gone through it at least seventy times at the expense of a great deal of time."

### Kepler's data (from Tycho)

• Which hypothesis do these data entail? (None!)



### Kepler: the real orbit is the ellipse that *best* fits the data.



• But why not this hypothesis?



• Or this one?



## Kepler's empiricism

• Nevertheless, Kepler was very sensitive to the data, as he was unhappy with a tiny difference of 8 arc-minutes between Ptolemy's predictions and Tycho's data.

For if I had thought I could ignore eight minutes of longitude, in bisecting the eccentricity I would already have made enough of a correction in the hypothesis found in Ch. 16. Now, because they could not have been ignored, these eight minutes alone will have led the way to the reformation of all of astronomy, and have constituted the material for a great part of the present work. (Astronomia Nova)