# Whence the quantum conundrum?

1. The philosophical lesson of quantum theory
    (a) Randomness?
    (b) Nonlocality?
    (c) Many worlds?
2. Brief history of classical physics 1600–1910
    (a) Galileo: eliminate all but primary qualities
    (b) Newton: particles and gravity
    (c) Laplace: the clockwork universe
    (d) Maxwell: electromagnetic waves
    (e) Einstein: relativity
    Locality and the speed of light
3. Elements of a classical worldview
    (a) Ontology (what is the world made of?)
    (b) Determinacy
    State description
    (c) Determinism
        i. Principle of sufficient reason
        ii. Laplace's demon
    (d) Locality (no "spooky action at a distance")
    (e) Separability
    The properties of a composite are determined by the properties of its parts
    (f) The aim of physics: what is a "good" theory?
4. Catastrophic fail
    (a) Blackbody radiation
    (b) Photoelectric effect
    (c) The Rutherford atom
5. Niels Bohr (1885–1962)
    (a) Energy levels and quantum leaps
    (b) Prediction of spectral lines
    (c) The periodic table

6. Cobbling together a new "theory" (1915–1930)

    (a) Matrix mechanics (Heisenberg 1925)

        i. *beobachtbare Grösse*
        ii. uncertainty principle and disturbance interpretation

    (b) Wave mechanics (Schrödinger 1925)

        i. *verdammte Quantenspringerei*
        ii. Schrödinger equation

    (c) Complementarity (Bohr 1927)

    (d) Hilbert space formalism (von Neumann 1926–32)
    No hidden variables theorem

7. Einstein-Bohr debates (1927–1935)

    (a) Photon box (1927)
    (b) Einstein-Podolsky-Rosen argument (1935)
    (c) Realism versus antirealism? Rational versus irrational? Determinism versus "god rolls dice"?

8. Bohr for dummies, a.k.a. Copenhagen/Orthodox interpretation (1935–)

    Collapse of the wavefunction

9. Heretics

    (a) David Bohm's "hidden variable" theory (1952)
    (b) Many worlds (Hugh Everett 1957)
    (c) Nonlocality (John Bell 1965)
    (d) "Quantum theory without observers" (Bell 1986)
    (e) Bell's disciples (1990-)

## Sean Carroll: physicists don't understand QM

1. What criteria for *understanding* does Carroll use to judge the current state of quantum physics? How does quantum physics — or how do quantum physicists — fail to meet these criteria? Do you agree with Carroll's criteria? What might motivate them?

2. What, for Carroll, would a good physical theory be like? What do you think motivates his vision? Do you agree with it?

3. What are some other vices that Carroll sees in how physicists use, and think of, QM? (Hint: look for where he uses words with negative connotations.) Do you think that these are necessarily vices? Could they be avoided?

## Stern-Gerlach experiments

### First experiment

Two magnets, perpendicular orientation. i.e. send “up” from spin-$z$ to a spin-$x$ magnet.

$$\begin{array}{ccccc} Z & \longrightarrow & X & \longrightarrow & D \\ \downarrow & & \downarrow & & \\ E & & D & & \end{array}$$

Phenomena: the detectors click individually (not at the same time), and in general there is a 50% chance of each detector clicking.

### Second experiment

Two magnets, same orientation. i.e. send “up” from spin-$z$ to a spin-$z$ magnet.

$$\begin{array}{ccccc} Z & \longrightarrow & Z & \longrightarrow & D \\ \downarrow & & \downarrow & & \\ E & & D & & \end{array}$$

Phenomena: the top detector always clicks, and the bottom detector never clicks.

## Maudlin: intro to book

1. Warm up (easy question): who are the bad guys in Maudlin’s story? Who are the good guys?
2. When you’re going through the text, note words with strong positive or negative connotations. (e.g. in application to a statement or theory, “clear” has a strong positive connotation.) For each such word, write down — in a sentence or two — what you think Maudlin means by it.
3. What does Maudlin mean by saying that quantum mechanics is not a theory? What does he think it takes to be a theory?