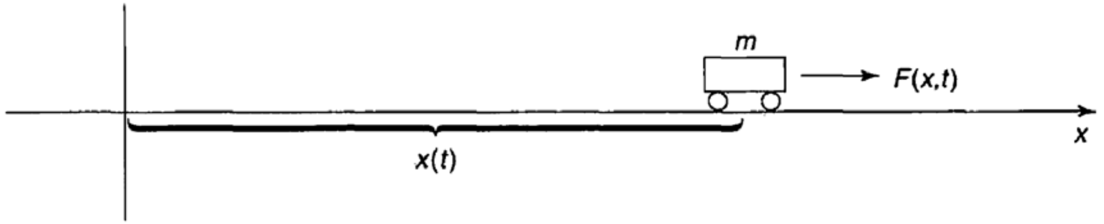
Introduction

In non-relativistic classical mechanics, Newton's law says

$$ma = F$$



It is a second order differential equation. Assuming the force is conservative (arises from a potential energy function *V(x)*, unlike friction) in 1D (for simplicity) it becomes:

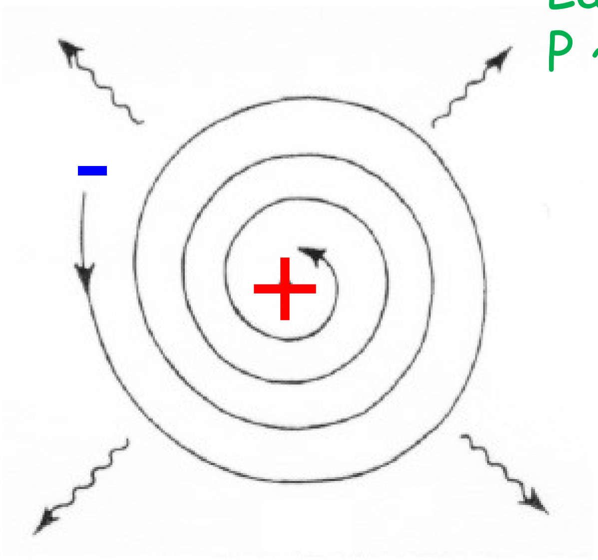
$$m\, d^2x/dt^2 = -\partial V/\partial x$$

Then, typically we solve this 2nd order differential eq. with initial conditions at *t=0*, namely *x(0)* and *dx/dt (t=0)*, and find *x(t)*.

From *x(t)* we get position, velocity, acceleration, kinetic energy, etc.

In addition, we have Maxwell's equations for electrodynamics.
All seems very nice and clear, right?

<u>However, at the atomic level classical physics does not work</u>

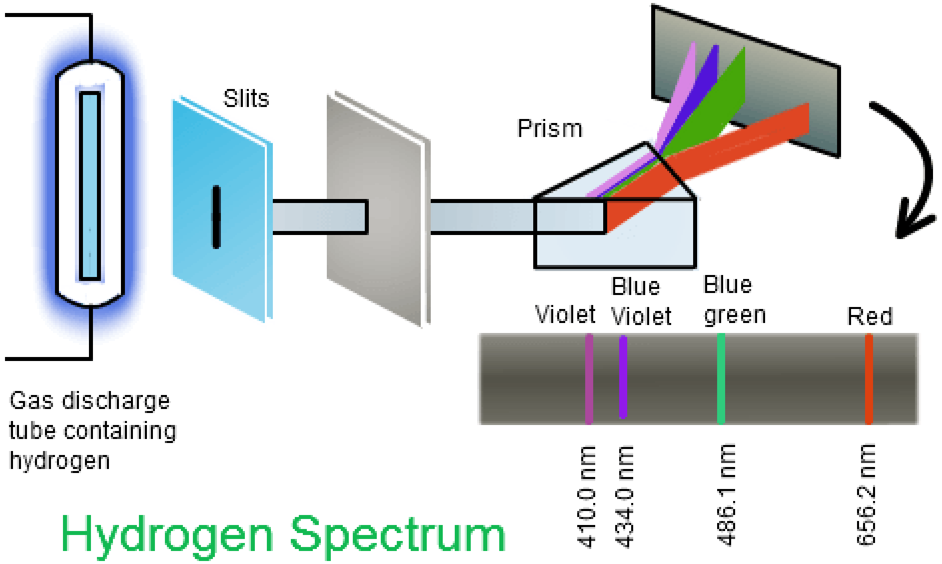


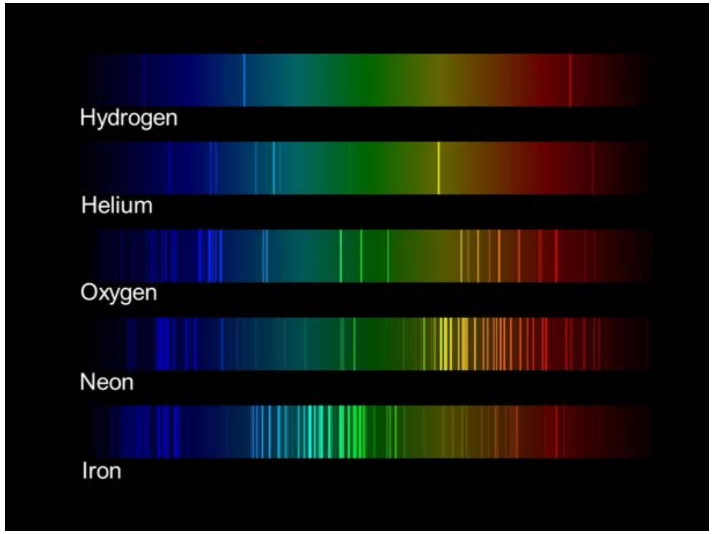
Larmor radiation
$P \sim a^2$

The classical view of an atom as a miniature "solar system" does not work because electron and proton are charged, unlike planets around the Sun.

Within classical electromagnetism (Maxwell eqs) charged particles in a circular orbit loose energy because they emit Larmor radiation. Lifetime estimated to be 10^{-10} seconds. Atoms would be unstable!

In addition, when hydrogen atoms inside a tube absorb energy, and then return the energy as light, the spectrum is found to be discrete, with just a few lines (Modern Physics class).





Classical physics has no explanation for this result at all.

We need a new physics **drastically** different from classical …

Chapter 1

Classical Mechanics must be replaced by Quantum Mechanics at short distances.

Instead of Newton's equation we will have the Schrödinger equation (Sch. Eq.)

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2 \Psi}{\partial x^2} + V\Psi$$

V is V(x,t) in general

New fundamental constant of Nature is introduced. The Planck's constant:

$$\hbar = \frac{h}{2\pi} = 1.054572 \times 10^{-34} \text{ J s}$$

Energy x time

The "wave function" $\Psi(x,t)$. This will be the most important quantity to calculate the whole semester.

Imaginary unit: we will deal with complex numbers.

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V\Psi$$

(plus boundary conditions and $\Psi(x,t=0)$)

Planck's constant.

Mass of particle, typically electron ($m_e = 9.1 \times 10^{-31}$ kg).

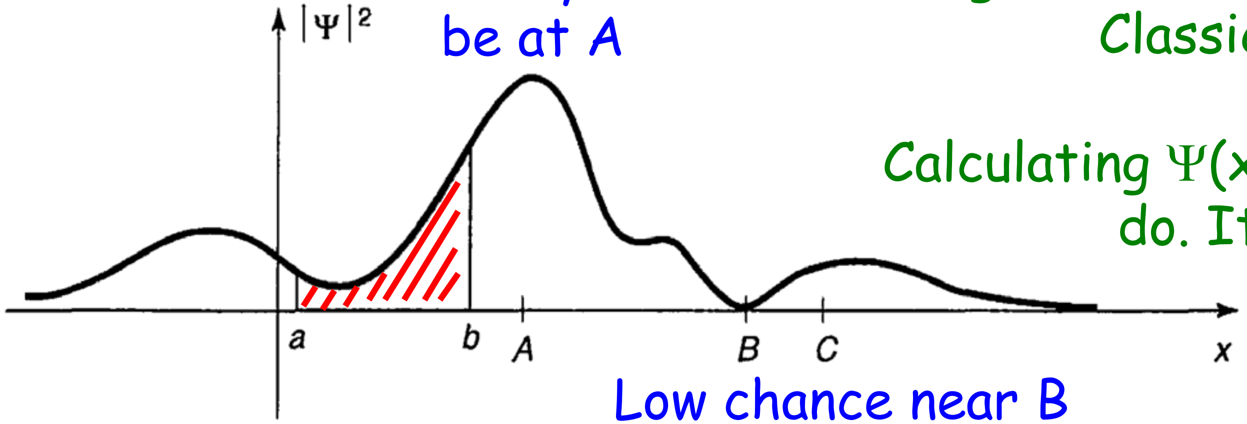
Potential $V(x,t)$ is given to you (e.g. harmonic oscillator or time-dependent electric field or 1/r H atom).

Check that all factors multiplying Ψ have the same units (example: units of $\hbar \times \partial/\partial t$ are Energy $\times$ time/time, same as V)

What is the wave function? In classical mechanics we need x(t), but $\Psi(x,t)$ is a function of x and t. It is **spread**. So it cannot be the position of the electron …

Book 1.2: Born's statistical interpretation

$$\int_a^b \underbrace{|\Psi(x,t)|^2}_{\Psi^*(x,t)\,\Psi(x,t)} dx = \left\{ \begin{array}{l} \text{probability of finding the particle} \\ \text{between } a \text{ and } b \text{, at time } t. \end{array} \right\}$$



Likely to be at A

Low chance near B
Unlikely at C

The statistical interpretation is "disturbing", because relies on probabilities. Classical mechanics does not.

Calculating $\Psi(x,t)$ is the best you can do. It is NOT our ignorance.

TOO early to start philosophical discussions, but following the book we will address: if I "measure" the position of a particle and is found at x=c, where was an instant before?

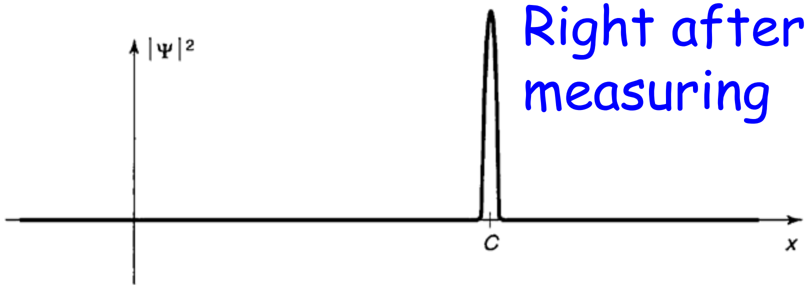
Realistic view: the particle was at x=c or very close. Thus, QM is incomplete since it did not predict it. There must be a more fundamental theory (Einstein's view: QM is incomplete).

Orthodox view: the wave function is the particle. "Measuring" is something peculiar … always done with a macroscopic object (virtually everybody accepts this view, plus confirmed by Bell's argument Ch. 12).

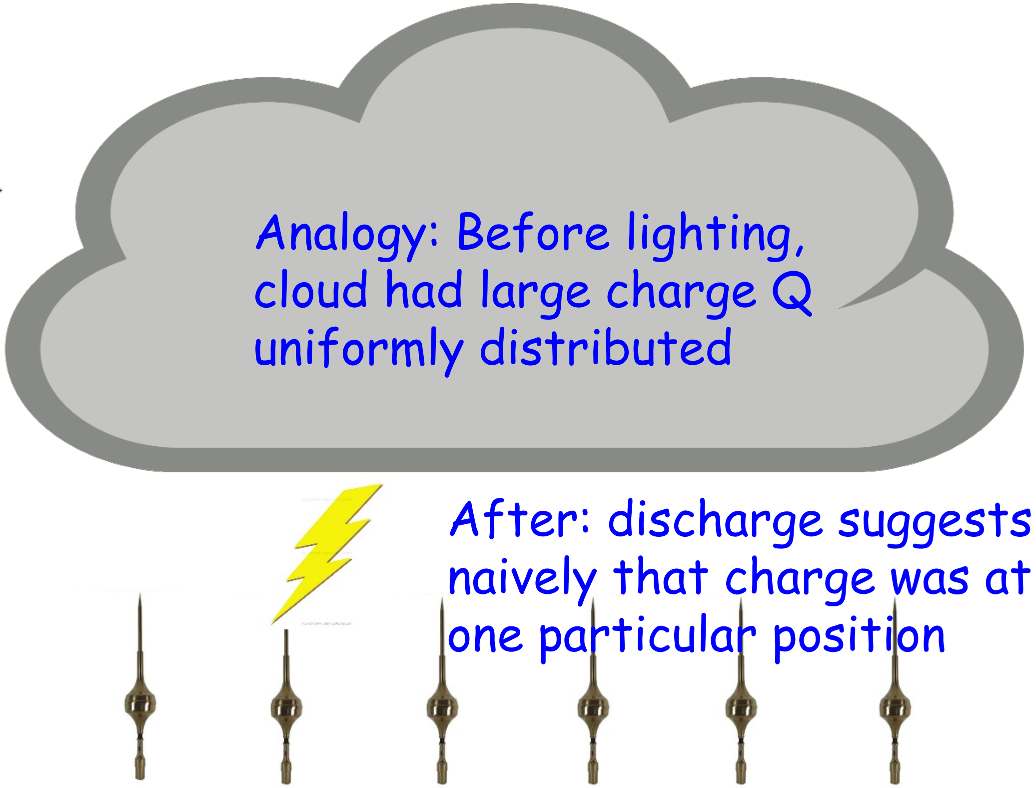
Agnostic view: the question cannot be verified experimentally, thus it is methaphysics.

… read about collapse of the wave function … if you are brave … page 6 book. We will return to this later.

It addresses the interaction of a quantum object, the electron, with a classical and large object, the measuring device. VERY difficult conceptually. Measuring is not trivial!



Right after measuring



Lightning rods are like a measuring device

Definitely QM is against "common sense".
At short distances, weird things happens!

Any one who is not shocked by quantum mechanics has not fully understood it. Niels Bohr

If you think you understand quantum mechanics, then you're not trying hard enough. Richard Feynman

Similar anti-common-sense behavior near large masses (general relativity), at huge distances (accelerating expanding universe), or at huge velocities (c is max).

The best approach is to become familiar with the formalism, understand the concepts and how to calculate, and … slowly … you get used to quantum mechanics.