Lecture 19

Fundamentals of Physics

Phys 120, Fall 2015

Quantum Physics III

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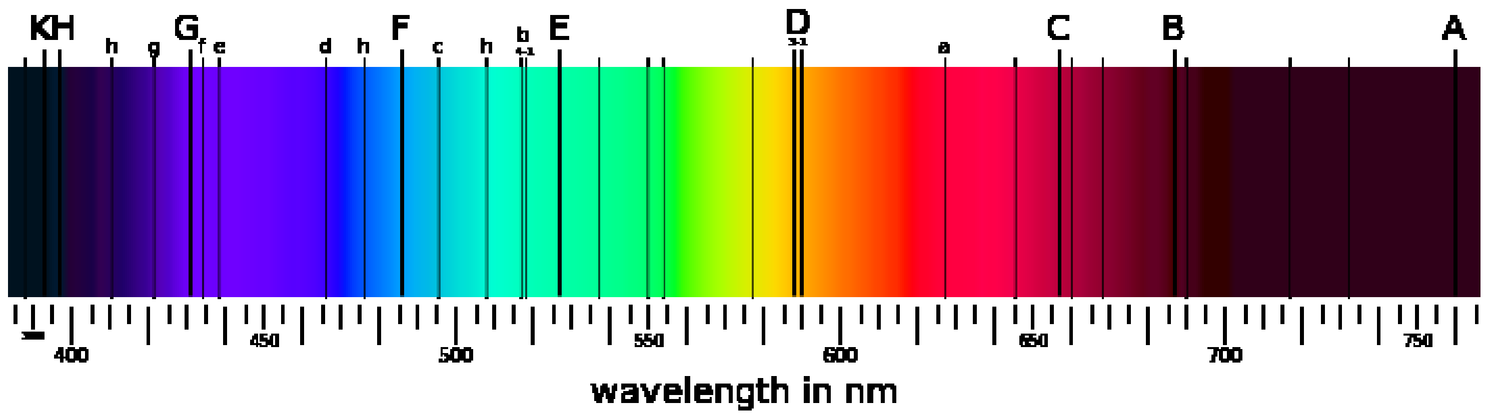


Overview

- Review of Quantum Mechanics so far.

- Spooky action at a distance

- Quantum reality

- How it all got started: atomic spectra

- The quantum mechanical atom

Review

- Real objects are fields (not waves or particles)
- Detection leads to a nonlocal collapse of the field
- Heisenberg's uncertainty principle highlights that our Newtonian view is untenable

The Nonlocality Principle

The Nonlocality Principle
Quantum theory predicts that entangled particles exhibit behavior that can be explained only by the existence of real nonlocal (that is, instantaneous and distant) correlations between the particles. That is, a physical change in one particle causes instantaneous physical changes in all the other particles that are entangled with that particle, no matter how far away those other particles may be.

Quantum computers

Quantum entanglement is quickly destroyed if the entangled particles contact the external world. But despite this Physicists are working on developing quantum computers where the local bits are in an entangled state.

Each bit will be a **qubit**, which have two states "0" and "1" just as a normal bit. But qbits can be in several states at once (just like the photon that goes through both slits). The advantage comes from calculations that are done on all states of the qubit at once. So a quantum computer with 3 entangled qbits will be doing the equivalent of $2^3 = 8$ calculations at once!

Concept check

How many simultaneous operations could a 10 qubit quantum computer perform?

a) 10

b) 100

c) 8

d) 64

e) 512

f) 1024

Concept check

If two electrons are entangled then

a) if one of the particles suddenly alters its wave packet, the other must also

b) they must exert forces on each other

c) they will become less entangled as they move further apart

d) both are part of a single matter wave

e) they will become more entangled as they move further apart

Reality in the quantum world

- Odd but not paradoxical
- Nonlocal
- quantized
- knowledge about pairs of quantities exclude each other: velocity/position, i.e. they are not fundamental.
- Observation: not human observation, but interaction with a macroscopic system.

Comparison of Newtonian and Quantum worldview

	Newtonian	Quantum
Atomism	Atoms form the fundamental reality. Newton called them "solid, massy, hard, impenetrable particles" that "never wear of break in pieces".	Newton's particles are not real. The reality are matter fields which are quantized. Atoms are not solid, they are mostly empty and consist of the quanta of matter fields. They are not indestructible: energy is conserved, but matter is not.
Predictability	The future is hardwired into the present. Once the universe got started everything had to develop exactly the way it did.	the detection process leads to fundamentally unpredictable results: measurements on identical systems do not give the same result. But large scale statistical quantities remain predictable.
Analysis	Science progresses by breaking down the world into its simplest component particles and understanding those.	Due to quantum entanglement one cannot reduce the world to simple components. The whole entangled system must be treated as one unit.

The post Newtonian worldview

Despite a century of quantum physics, a post-Newtonian worldview had not yet evolved.

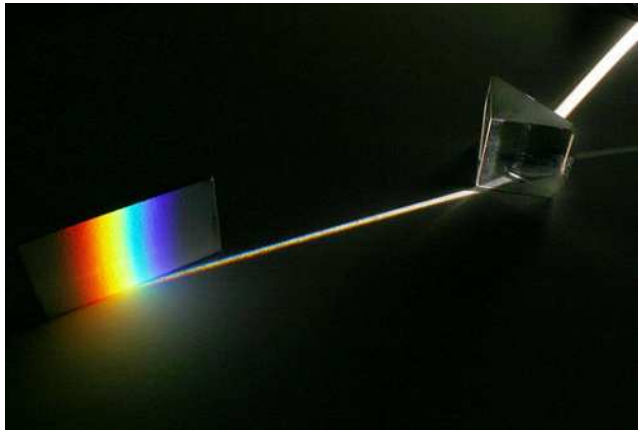
This is likely due to the fact that an accurate intuitive understanding of quantum mechanics remains elusive for most of humanity.

The Newtonian worldview, however, is closely based on the views already expressed by the atomists Democitus and the Epicureans, and it is much easier to develop an intuitive grasp of the idea of a world made up of interacting particles following clear, deterministic rules.

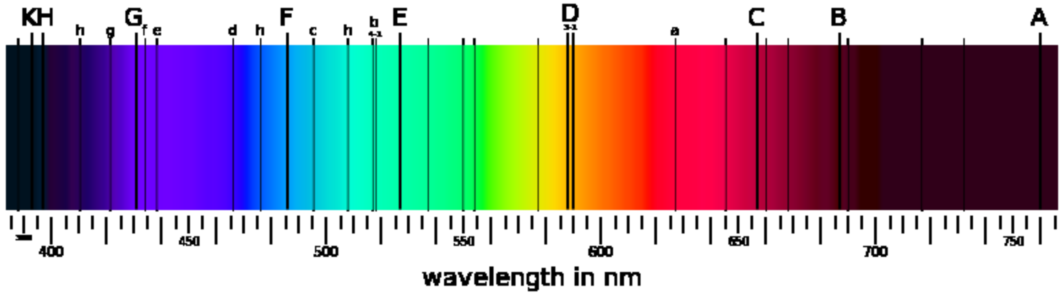
How it all got started: Atomic spectra

We focus on observations first, than we turn to the explanations.

When light moves through a prism, it gets separated into a rainbow of colors. This phenomenon has been known at least since Roman times, but Newton is credited with studying this phenomenon carefully.

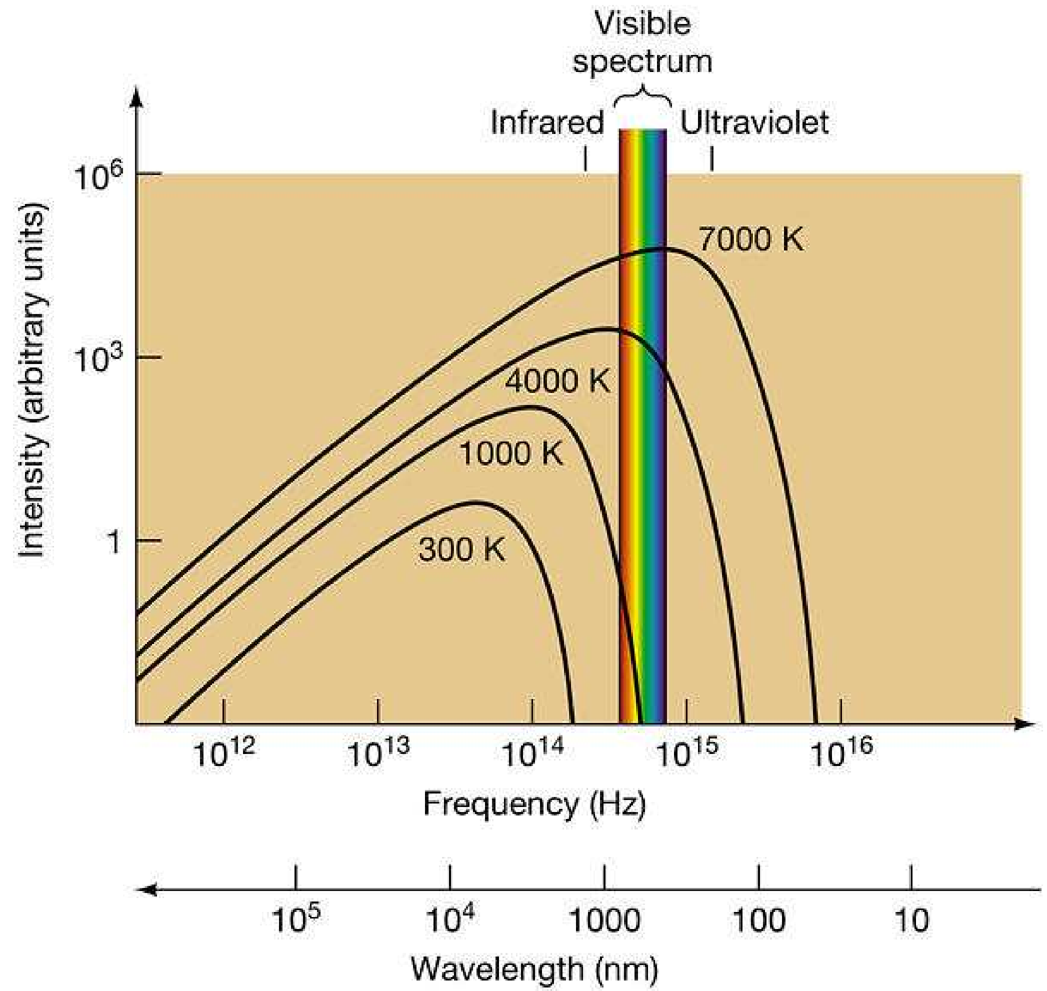


When studying sunlight Joseph von Fraunhofer (1787-1826) noticed that strangely there are some bits of light missing:



The spectrum of a hot object

Everything emits some Electromagnetic radiation at different frequencies. On the right you see the intensity of light of different frequency emitted by a body at different temperatures. The hotter the object, the larger the intensity, but even more important the hotter the object, the higher the frequencies (i.e. energy: E=hf) of the emitted light.



Concept check

You might have noticed that as you heat a metal hot plate, it first glows dark red and then becomes brighter and whiter. Just before it begins to glow, we might expect such a hot plate to emit

a) ultraviolet radiation

b) infrared radiation

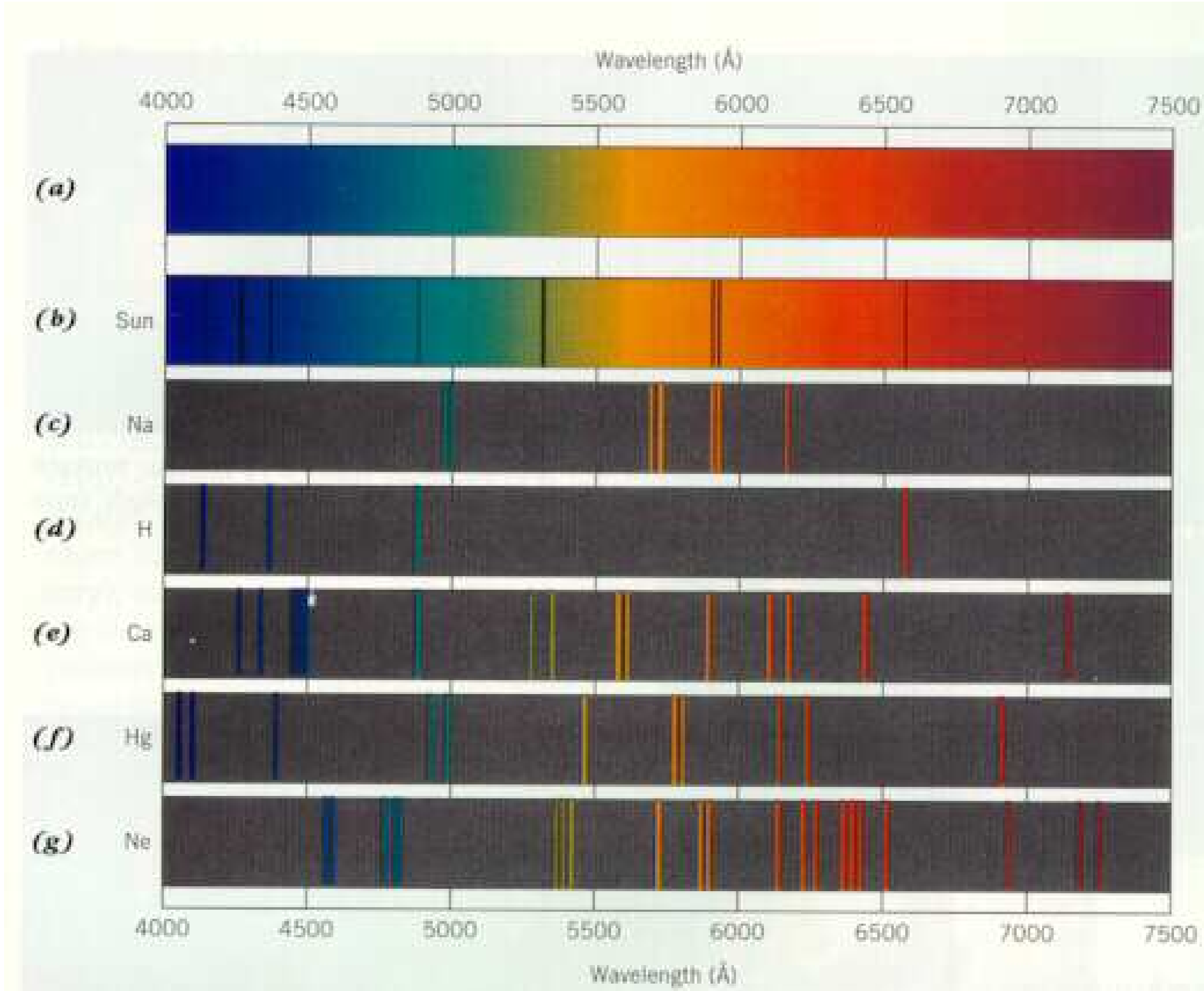
c) no radiation at all

Different lightsources

When looking at the spectra of light from different sources, it became clear that e.g. flames showed different distinct lines in the spectra, and, depending on the material that was being burned, the lines differed!

So just by looking at the light of flames (and spectral analysis of it) you can distinguish the material that is being burned!

The spectrum of gases



The Balmer series

Johann Balmer ( ) discovered in 1885 that the frequencies of the lines of hydrogen can be described as a series related to integers!

$$\lambda = (3.6 \cdot 10^7 m) \frac{n^2}{n^2 - 2^2} \tag{1}$$

for integers $n > 2$.

But is was impossible to understand the reason for this intriguingly simple answer (and other atoms are more complicated).

Concept check

As the hot plate in the preceding concept check goes from dark red to white, its spectrum would

a) change from a spectrum containing only red lines to one containing only white lines;

b) change from a spectrum containing only red lines to one containing many different colors;

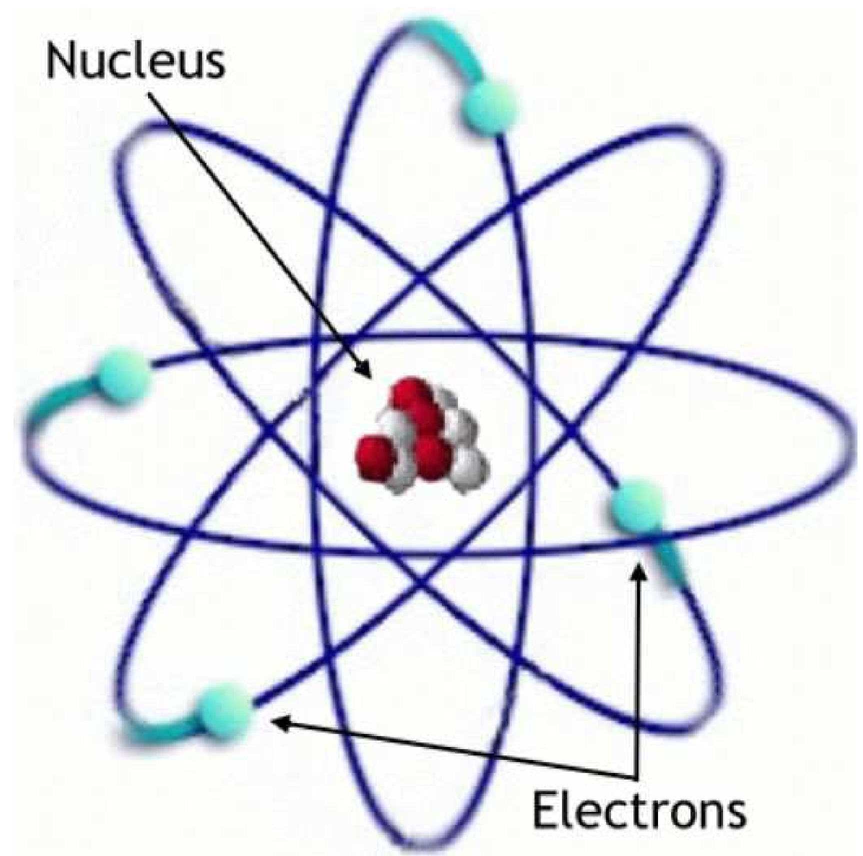
c) change from a dim continuous red spectrum to an intense continuous white spectrum;

d) change from a dim continuous red spectrum to an intense spectrum that included all the colors.

Problems with the planetary model

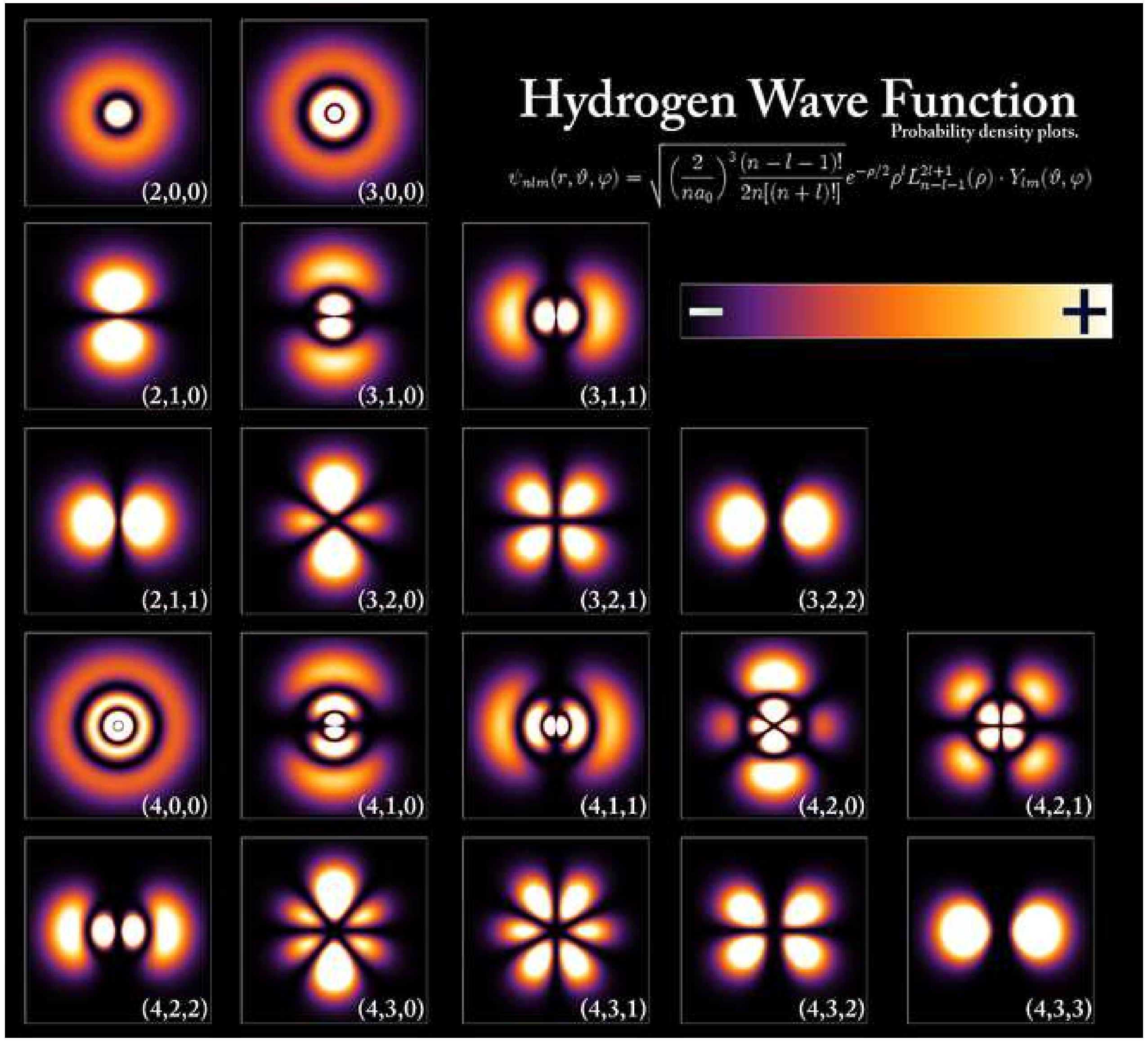
Electrons that move in a circle should radiate, i.e. emit energy! This would mean that the planetary atom would be unstable.

Also we saw that for more than one electron there are no stable solutions to Newtons equations (in our computational Physics lecture).

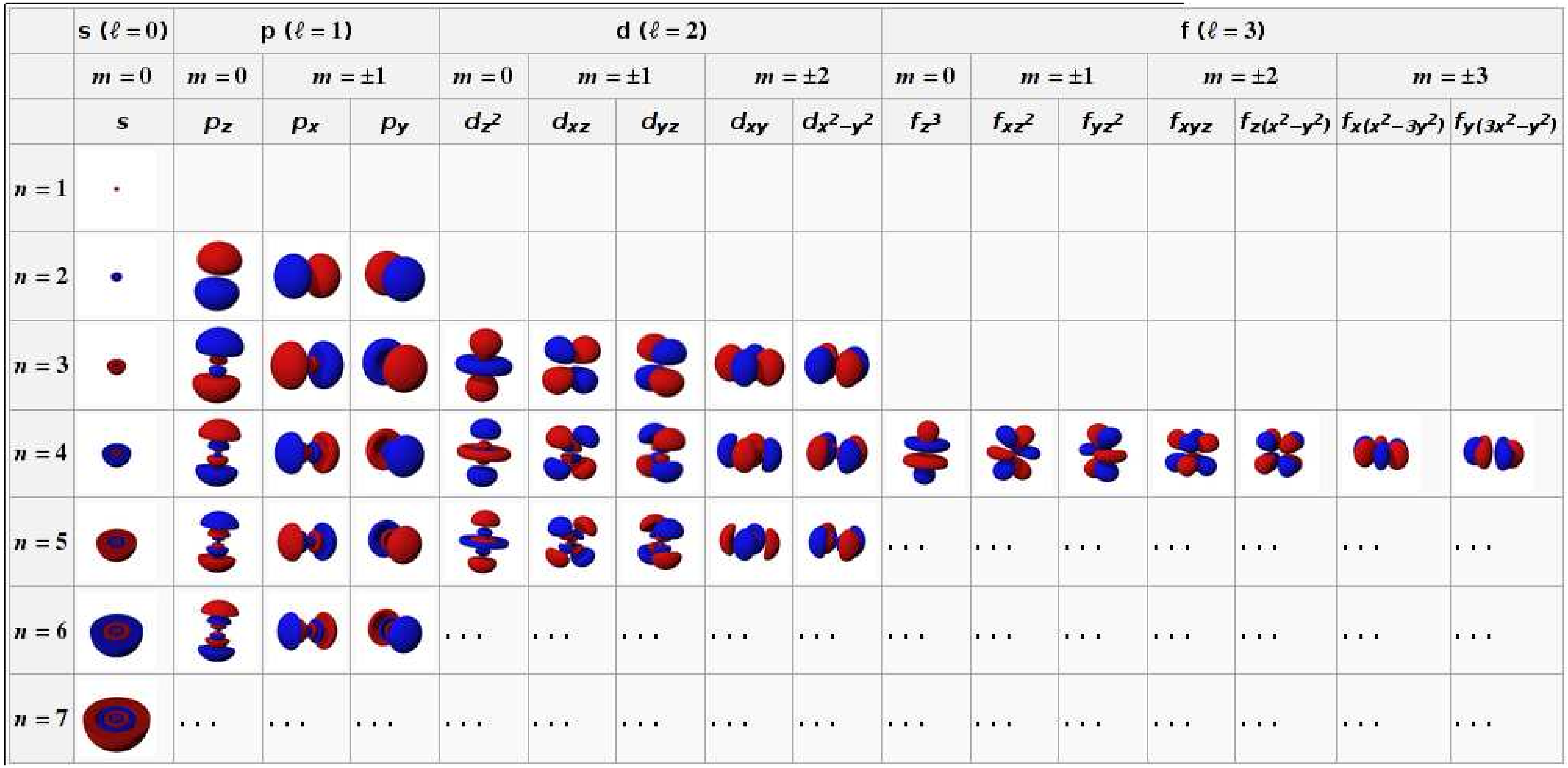


The quantum atom

The solution is given by solving the Schrödinger equation for the electron wave function. The solution is a probability density for finding an electron at a certain point in space. There are solutions only for certain discrete values of the electron energy, and the discrete transitions between these energies correspond to the light-frequencies observed in the spectrum: $E_n - E_m = hf_{n,m}$.

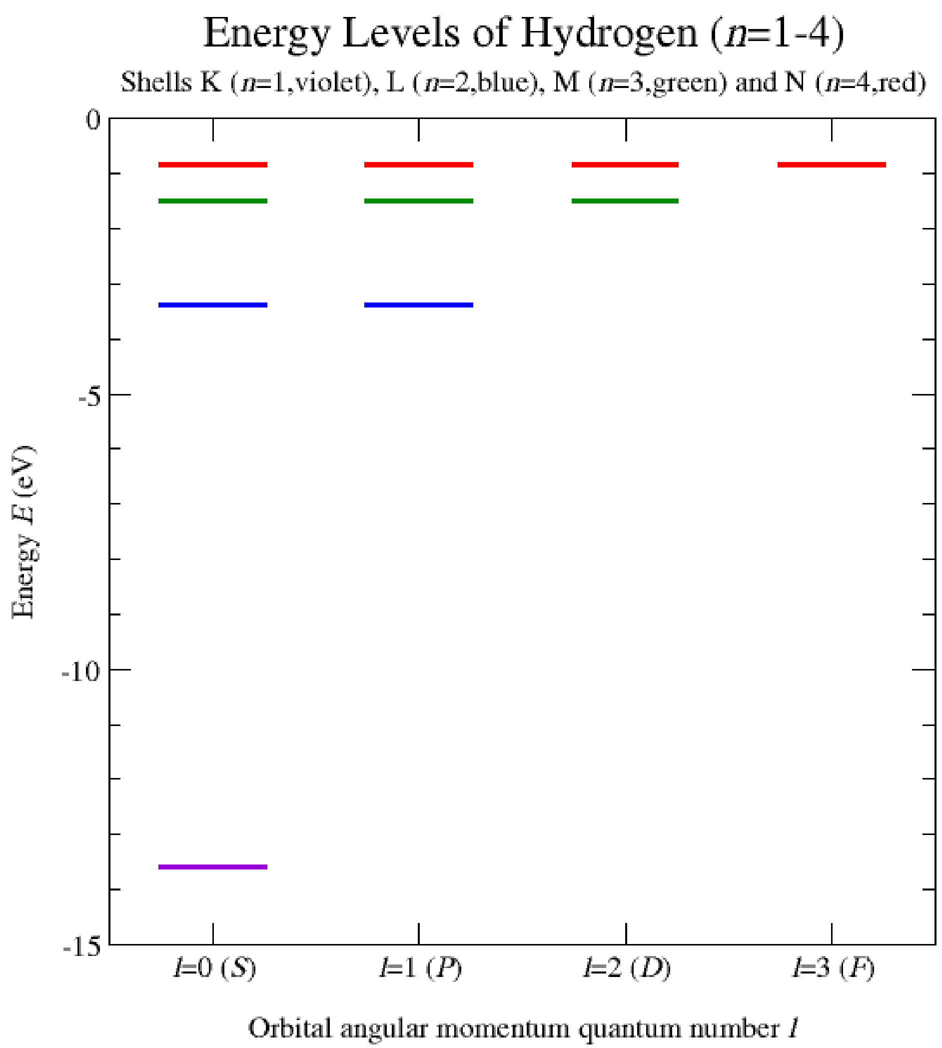


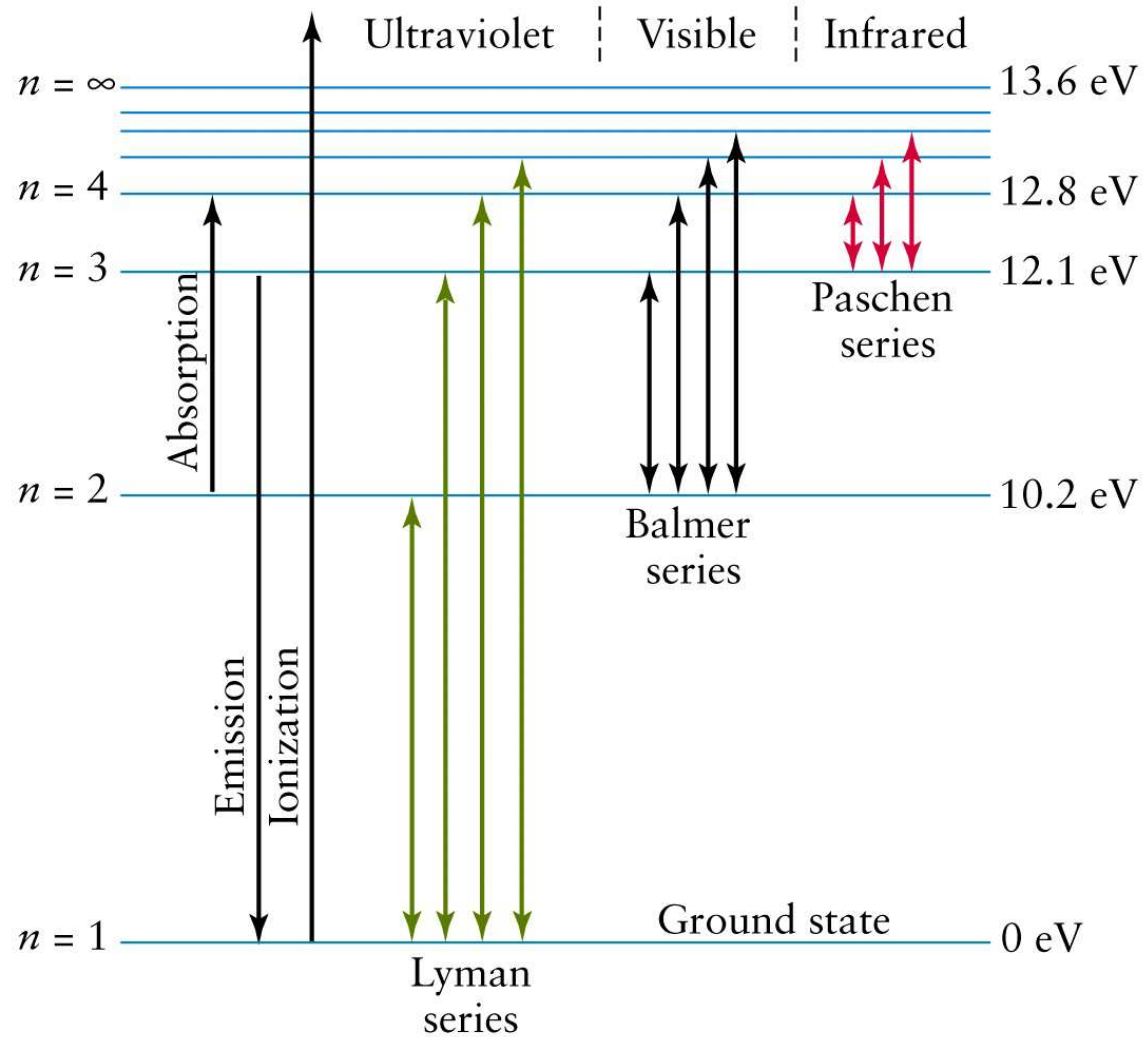
The orbitals in 3d



	$s\ (\ell=0)$	$p\ (\ell=1)$			$d\ (\ell=2)$					$f\ (\ell=3)$						
	$m=0$	$m=0$	$m=\pm1$		$m=0$	$m=\pm1$		$m=\pm2$		$m=0$	$m=\pm1$		$m=\pm2$		$m=\pm3$	
	s	p_z	p_x	p_y	d_{z^2}	d_{xz}	d_{yz}	d_{xy}	$d_{x^2-y^2}$	f_{z^3}	f_{xz^2}	f_{yz^2}	f_{xyz}	$f_{z(x^2-y^2)}$	$f_{x(x^2-3y^2)}$	$f_{y(3x^2-y^2)}$
$n=1$																
$n=2$																
$n=3$																
$n=4$																
$n=5$										...	...	...	...	...	...	...
$n=6$					...	...	...	...	...	...	...	...	...	...	...	...
$n=7$		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Energy levels and radiation





Energy radiation

The **ground state** is the state with the lowest energy. Other states are called **excited states**. The previous diagram is an **energy-level diagram**. It illustrates the "digital" nature of an atom. To radiate energy, the atom must undergo a **quantum jump**.

When the electron undergoes a transition, it will emit a photon with the energy corresponding to the difference between the two energy levels:

$$hf = \text{(energy of high-energy state)} - \text{(energy of low energy state)}$$

We know that **Schrödinger's equation** is reliable by the fact that it correctly predicts the atomic spectra (as well as other phenomena).

For the hydrogen atom the Energy levels are given by

$$E_n = \frac{13.9eV}{n^2} \tag{2}$$

Concept check

In the previous slide, which transition corresponds to the photon with the highest frequency?

Concept check

How many different frequencies can be created by quantum jumps among only the lowest six energy levels of hydrogen?

a) 6

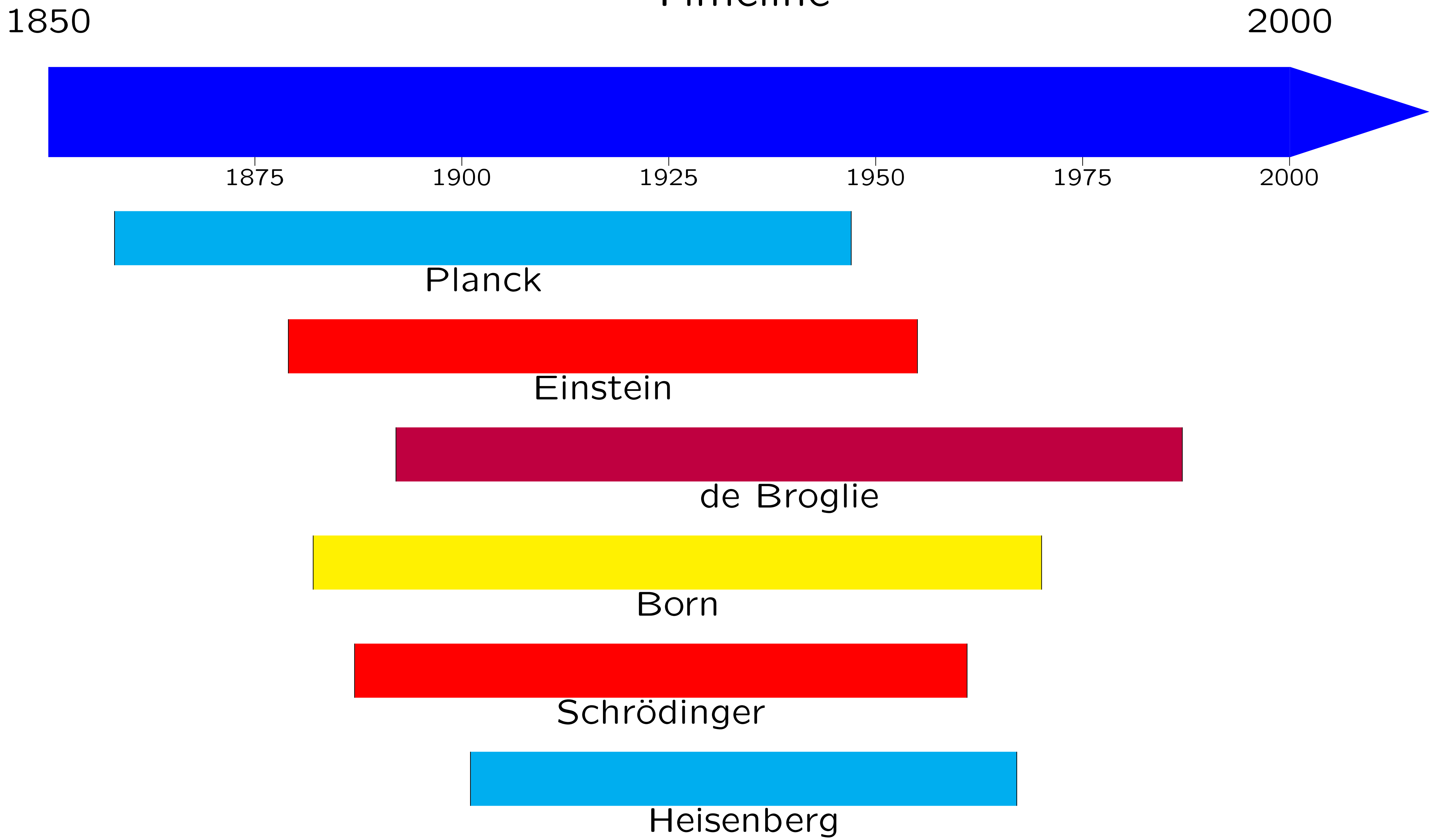
b) 5

c) 10

d) 14

e) 15

Timeline


1850
2000
1875
1900
1925
1950
1975
2000
Planck
Einstein
de Broglie
Born
Schrödinger
Heisenberg

Conclusions

Do you have any questions about quantum mechanics before we move on to the next chapter?