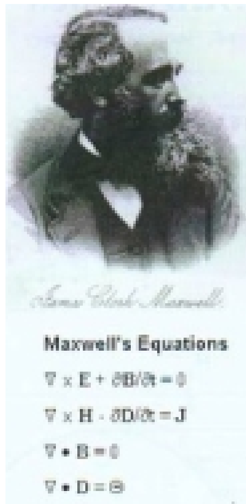
Quantum Theory of Radiation and Matter

around 1900 Scientists thought they knew it all!
  except (of course)
  for a few minor details

Newton's Laws
  Mechanics, gravity
Maxwell's Equations
  Electromagnetism
Thermodynamics
  Statistical Mechanics



Numerous experiments could not be explained

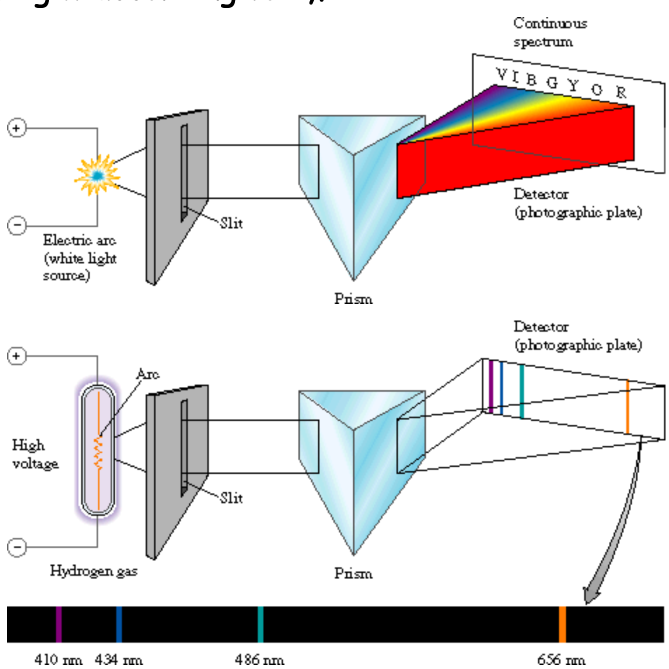
the accepted **laws** would occasionally fail!
  large distances, fast speeds ⇒ **Relativity**
  small distances, atomic sizes ⇒ **Quantum Mechanics**

Atomic Spectra

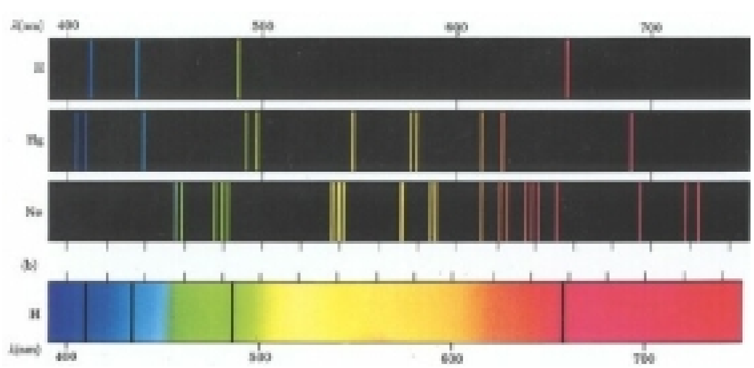
spectrograph separates light according to λ,f

continuous spectrum
  sun
  hot filament

line spectrum
  each element unique
  fingerprint
    for identification



now spectrographs use
diffraction grating
  mirror etched with
  fine lines
  separates λ

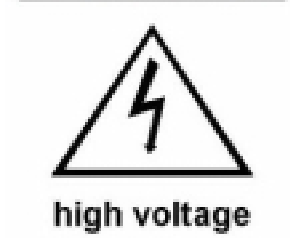


Some materials give off light when "excited"
i.e. when they gain extra energy (gas discharge above)
Fluorescence - light for a very short time (~msec)
Phosphorescence - (glow-in-the-dark) lasts minutes - hours

Radiation and Radioactivity - mysterious "rays"
smashing as an experimental method

use electric potential - High Voltage
to accelerate charged particles
smash them into something

noticed that nearby
fluor/phosphorescent screens
would glow!

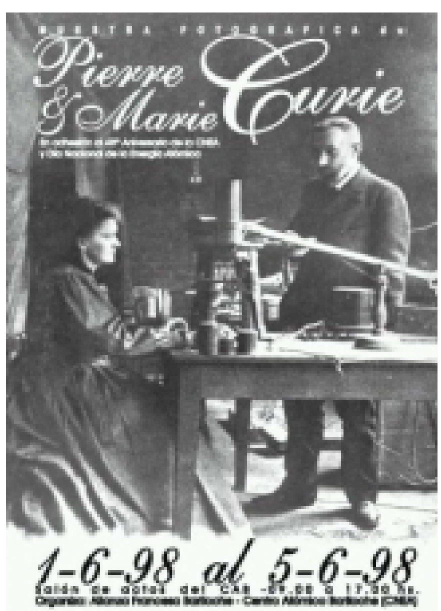


some rare materials - radium, uranium
would also cause screens to glow!

X-Rays - Roentgen
November 8, 1895
X = unknown
electromagnetic radiation
$\lambda \sim 1$ Å = 10 nm
penetrates many materials
exposes film in dark

Radioactivity
release of energy from
an unstable atomic nucleus

Marie and Pierre Curie
Nobel prizes
Marie twice!



classification into different types
can electric or magnetic fields
bend path of the "rays"?

α **ALPHA particles** - "heavy" positive charge
He nucleus - 2 protons + 2 neutrons
β **BETA particles** - "light" negative charge

high energy electrons

γ **GAMMA particles** - no observable charge or mass

very high frequency (small λ) radiation ⇒ **waves**

more energetic than X-rays

CATHODE RAYS from CRT (Cathode Ray Tube) TV/monitor

= electrons = β particles

Path of charged "rays" is deflected (bent or changed)
by electrically charged plates or magnetic fields.

Remember Electromagnetic spectrum!

Early Models of the Atom

Neutral - must have equal positive and negative charge

J.J. Thomson (shown with Rutherford)

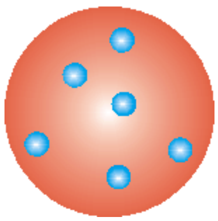
discovered electron in 1897

early cathode ray tube

plum pudding model of the atom

electrons as raisins

in continuous positive pudding



Rutherford Model of the Atom

test of how electric charge

distributed in solids

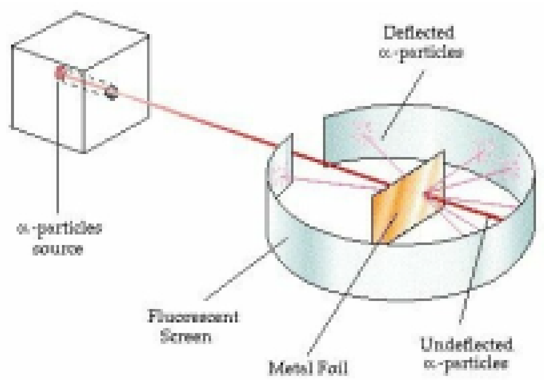
α particles shot at gold foil

most went straight through

or with small scattering

but a few

came straight back!



Conclusion positive charge must be highly concentrated!

then light electrons must "orbit" positive nucleus

as planets around sun

Rutherford's model of the atom

Problem:

moving charges lose energy by radiation

Maxwell's equations

electrons would fall into nucleus

atoms would collapse

Why don't electrons in "orbits" radiate energy?

Planck's Quantum Hypothesis

LIGHT acts as a
- **WAVE** - electromagnetic radiation
- **PARTICLE** - PHOTON or quantum

known as **DUALITY**

nature doesn't follow our prejudices

Energy of Quantum (photon) proportional to Frequency

$E = hf$ h = Planck's constant = 6.63×10^{-34} joule-s

for light

$c = \lambda f$ so $f = c/\lambda$ and $E = hc/\lambda$

Energy of a photon (light quantum) depends only on f (or λ)

NOT on brightness of light

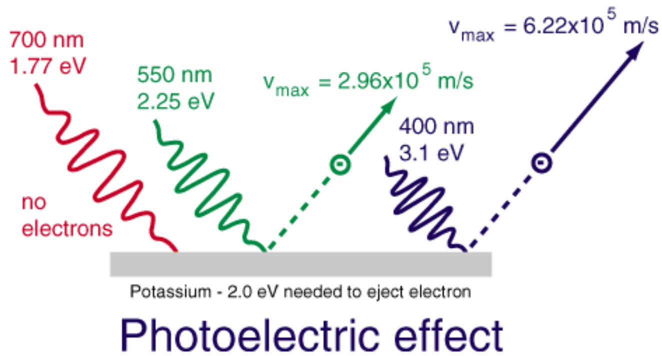
brightness ⇒ number of photons/sec

Photoelectric Effect

explained by Einstein ⇒ Nobel Prize

shine dim high f light (BLUE) on a metal:
Electrons emitted!

shine bright low f light (RED) on same metal:
No electrons emitted!



Metal:

work function W = minimum energy needed to eject electron

related to L_v

measured in **eV** (electron volts) small unit of energy

$1\text{ eV} = (1.6\times10^{-19}\text{ C})(1\text{ V}) = 1.6\times10^{-19}$ joule

low f RED light $hf < W$, electrons remain trapped!

high f BLUE light $hf > W$, electrons ejected!

In the photoelectric effect, light behaves as a particle (photon) with energy hf.

In dispersion through a prism, light behaves as a wave with wavelength λ.

PHONONS - quantum particles of sound.

Matter Waves - Duality - Louis De Broglie

If light (a wave) can behave as a particle (photon),
then particles must also behave like waves.
The quantum wavelength of a particle
depends on its velocity v and mass m:

$\lambda = h/mv$ mv = momentum

Note: quantum effects involve h (Planck's constant).

A bullet of mass 10 gm travels at 1000 m/s, what is λ?

$\lambda = h/mv = (6.63\times10^{-34}\ js)/(10^{-2}\ kg)(10^{3}\ m/s) = 6.63\times10^{-35}\ m$

For macroscopic (normal, bigger than microscopic) objects
quantum λ too small to have observable effects.

Electrons in atom ⇒ standing waves in a string
lowest energy level ⇒ fundamental frequency
only certain f (energies) allowed

Bohr Energy-Level Atom explains atomic spectra

Electron "orbits" have different sizes
larger orbits ⇒ larger energy E
Quantum **resonance**: wavelength must match size
only certain sizes/energies, unlike planets around sun
allowed energies are **quantized** (discrete, not continuous)
called **energy levels**, or permitted orbits
depend on Z, number of protons in nucleus

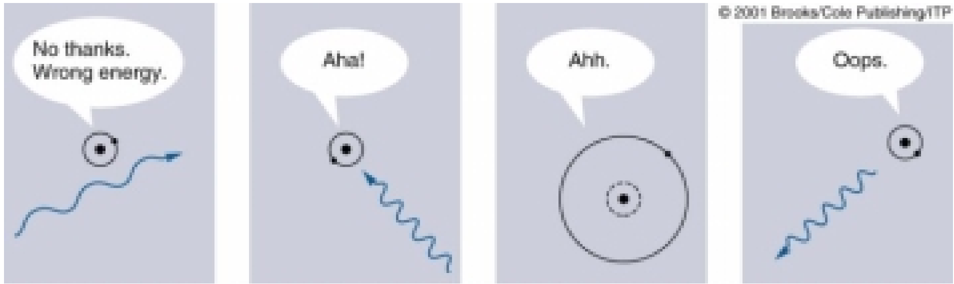
Excitation of Atoms

energy is required to move from one level to another
Upward Transition electron gains energy

$\Delta E = E_{upper} - E_{lower}$ very precise

energy can come from
1) collision with other atoms
2) **absorption** of a electromagnetic **photon**
with exactly the correct energy/wawelength

$\Delta E = E_{photon} = hc/\lambda$



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Downward Transition - **Emission** - atoms are lazy (like people!)

short time in excited upper level ~ 10^{-9} to 10^{-6} sec.

excited electron falls back to **ground state** (lowest energy state)

emits a photon with $E_{photon} = \Delta E = hc/\lambda$

same energy for emission as needed for absorption

but direction random

explains atomic spectra

emission and absorption lines at same λ