Physics 100 - March 5, 2007

Last time — quantum uncertainty

Schrödinger's equation

Wave equation for matter waves → $\psi(x)$

Mathematics a bit different from other types of waves

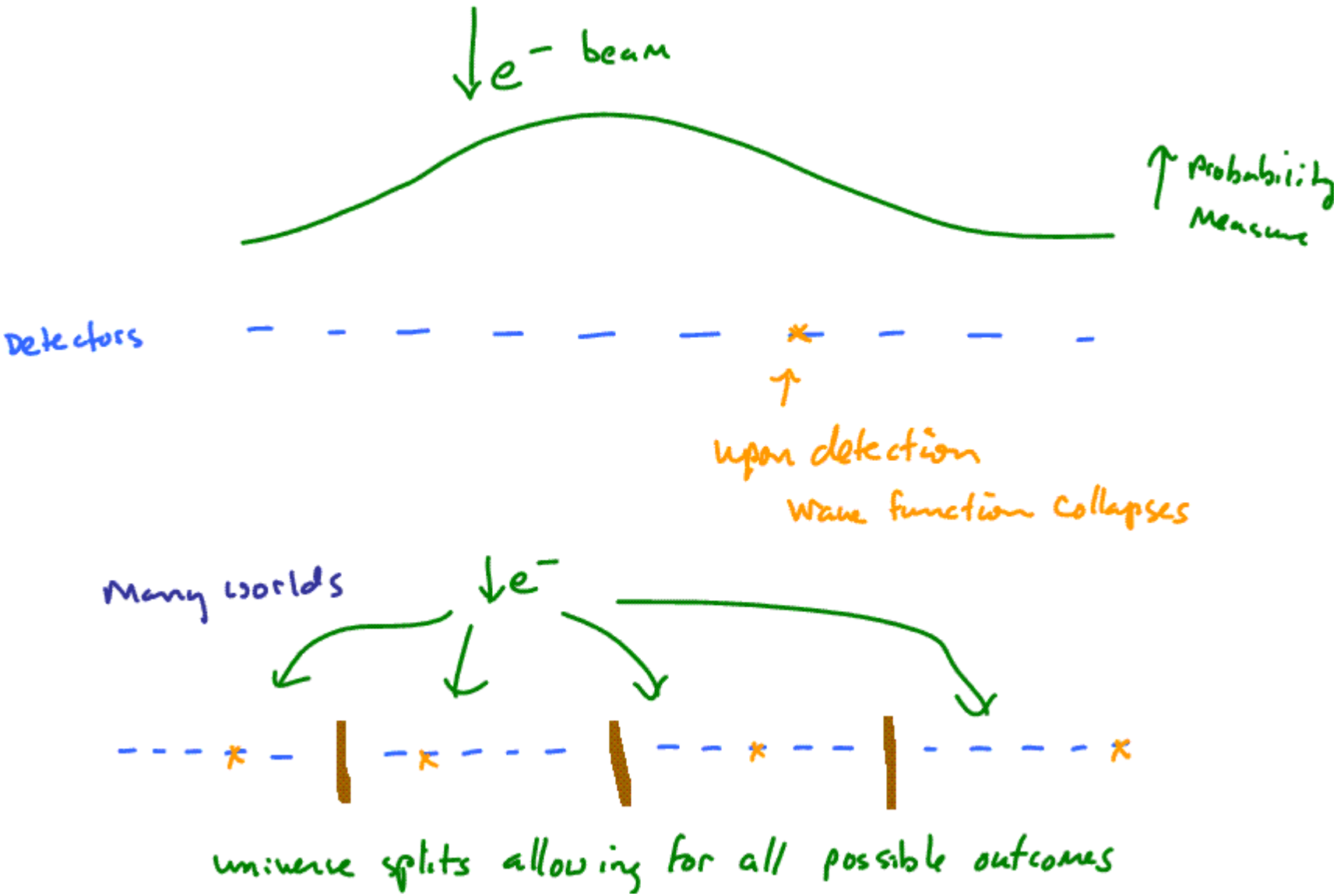
More difficult to interpret ... less intuitive

Copenhagen Interpretation (1927)

↳ Probabilistic

until observation particle only defined in terms of probabilities. Not in a definite STATE

$\psi^2 \sim$ probability


e⁻ beam
Probability
Measure
Detectors
upon detection
wave function collapses
Many worlds
e⁻
universe splits allowing for all possible outcomes

Heisenberg's Uncertainty Principle

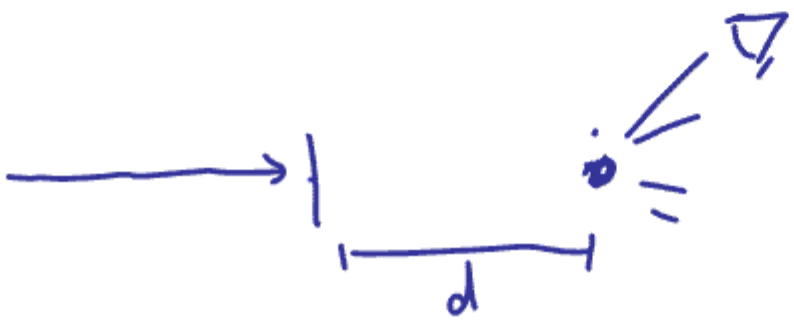
$$\Delta x \, \Delta p \leq h/2\pi \qquad \Delta E \, \Delta t \leq h/2\pi$$

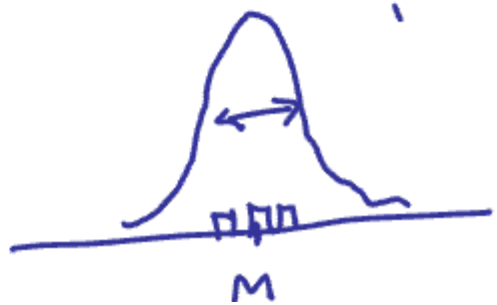
Huge implications

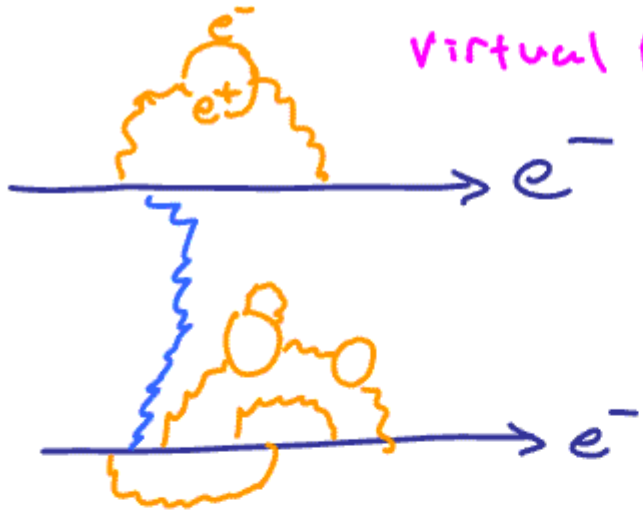
limits predictability in universe

Allows for breaking of conservation of energy so long as done for a very short time

$E = mc^2$







Virtual particles

$$F \sim \frac{q_1 q_2}{r^2}$$

Quantum Field theory – views the essence of forces to be the exchange of virtual particles

These only exist as quantum fluctuation as allowed by Heisenberg's Unc. Princ

$$\Delta E \Delta t \leq \frac{h}{2\pi}$$

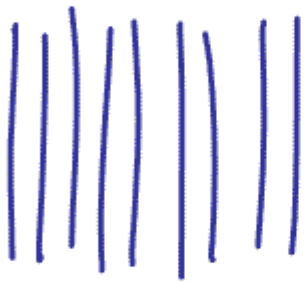
We'll discuss this much more in future classes

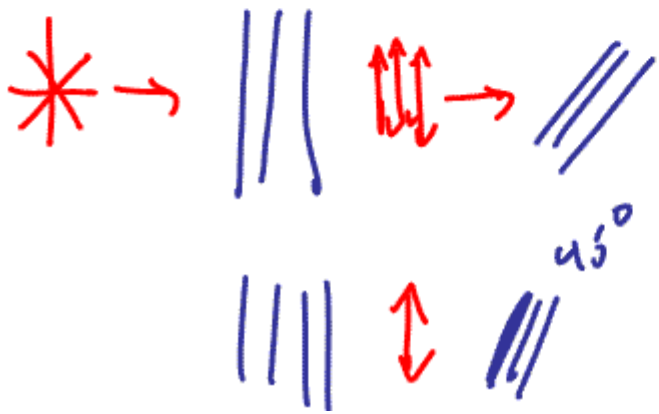
Polaroid
Sheet demo

EM wave

Polaroid filters

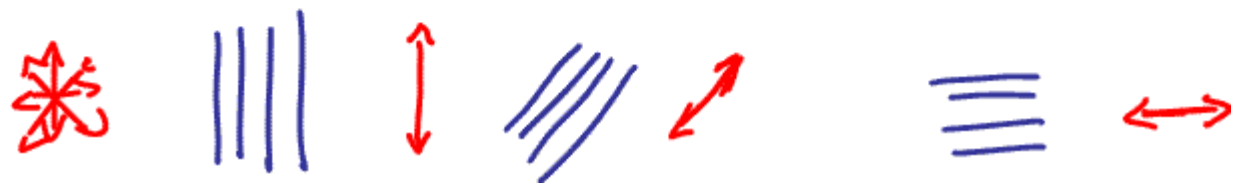
Polarization





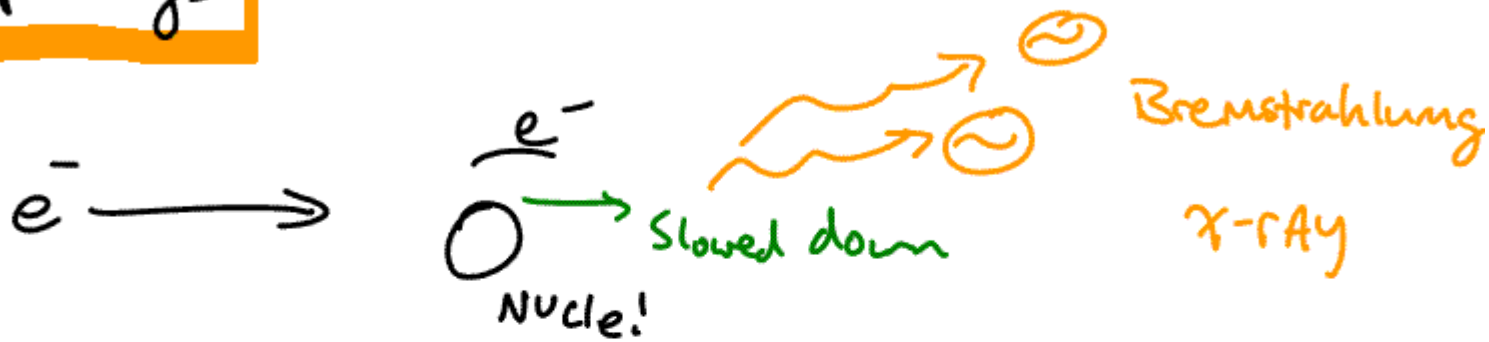
No light


nothing

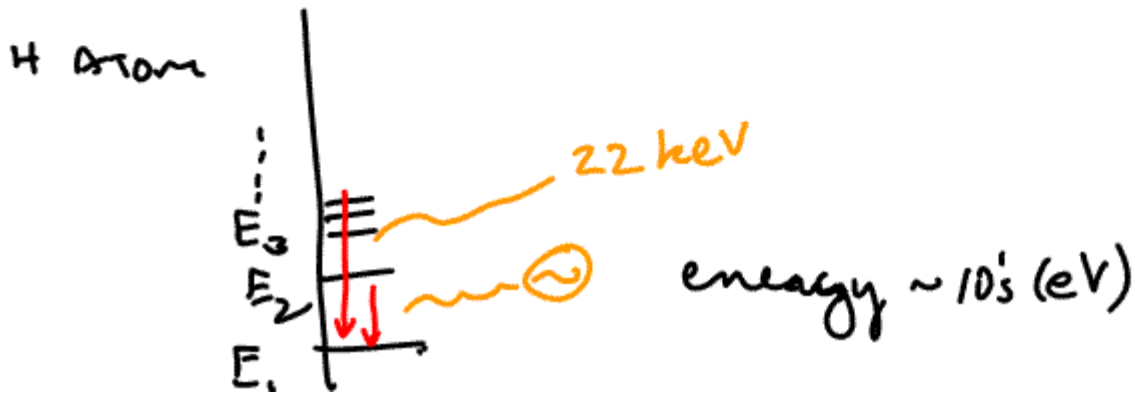


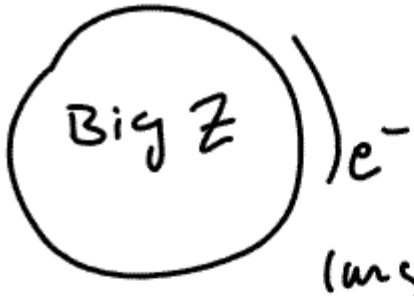
Wonders of layer 2

X-rays



Chged particle
Massively decelerated





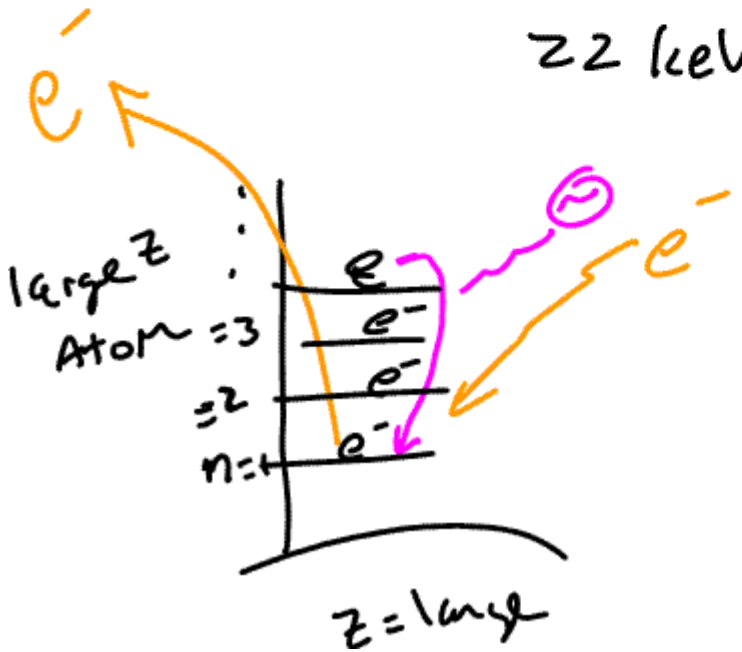
large Coulomb force

ionization energy large for inner shells

Z = 40 Zirconium

Ionization energy for n=1 e^-

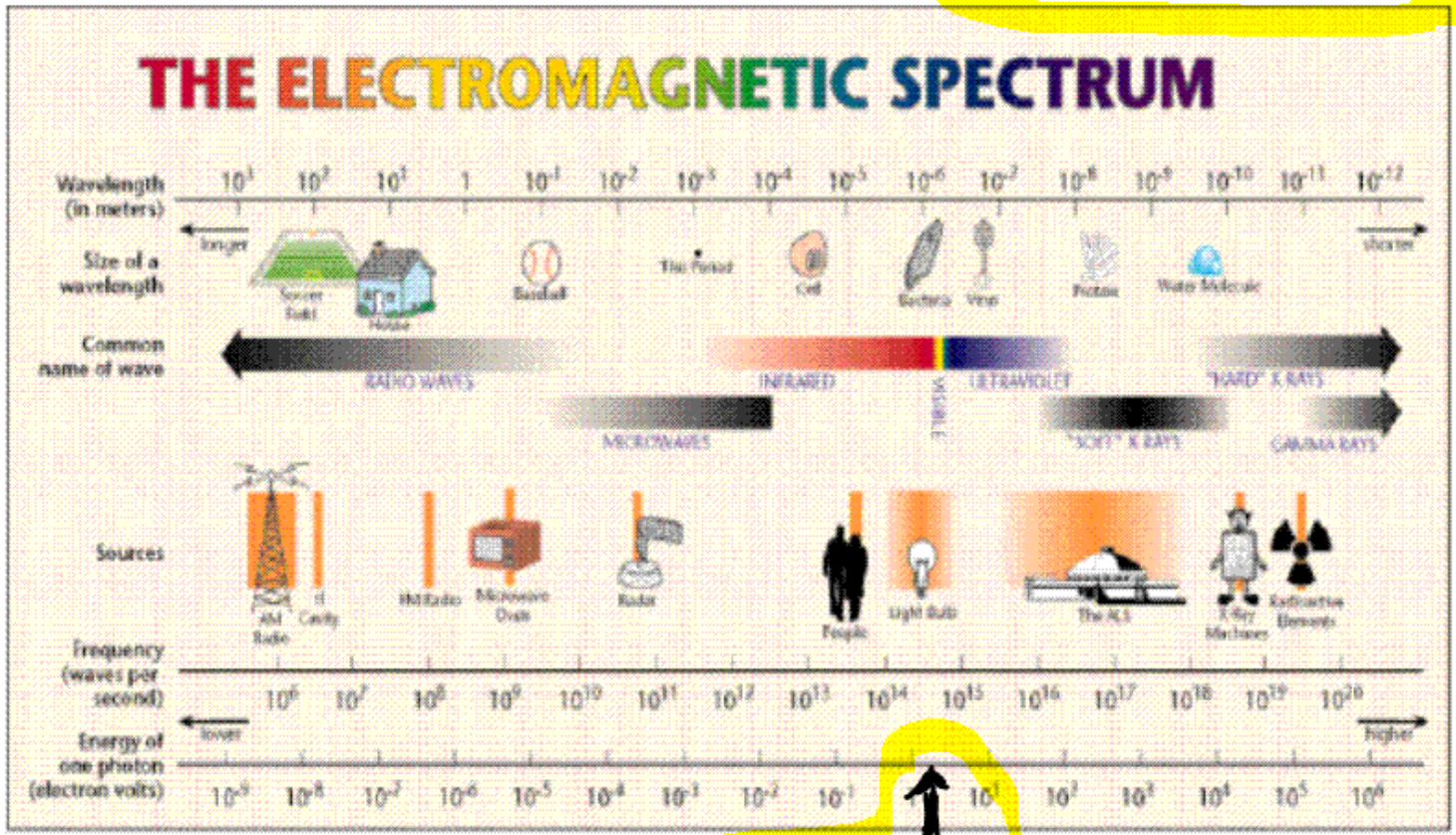
22 keV = 22,000 eV



X-rays

X-rays $\lambda \sim 10^{-8} - 10^{-12}$ m

$E = h\nu \sim 100 - 100000$ eV

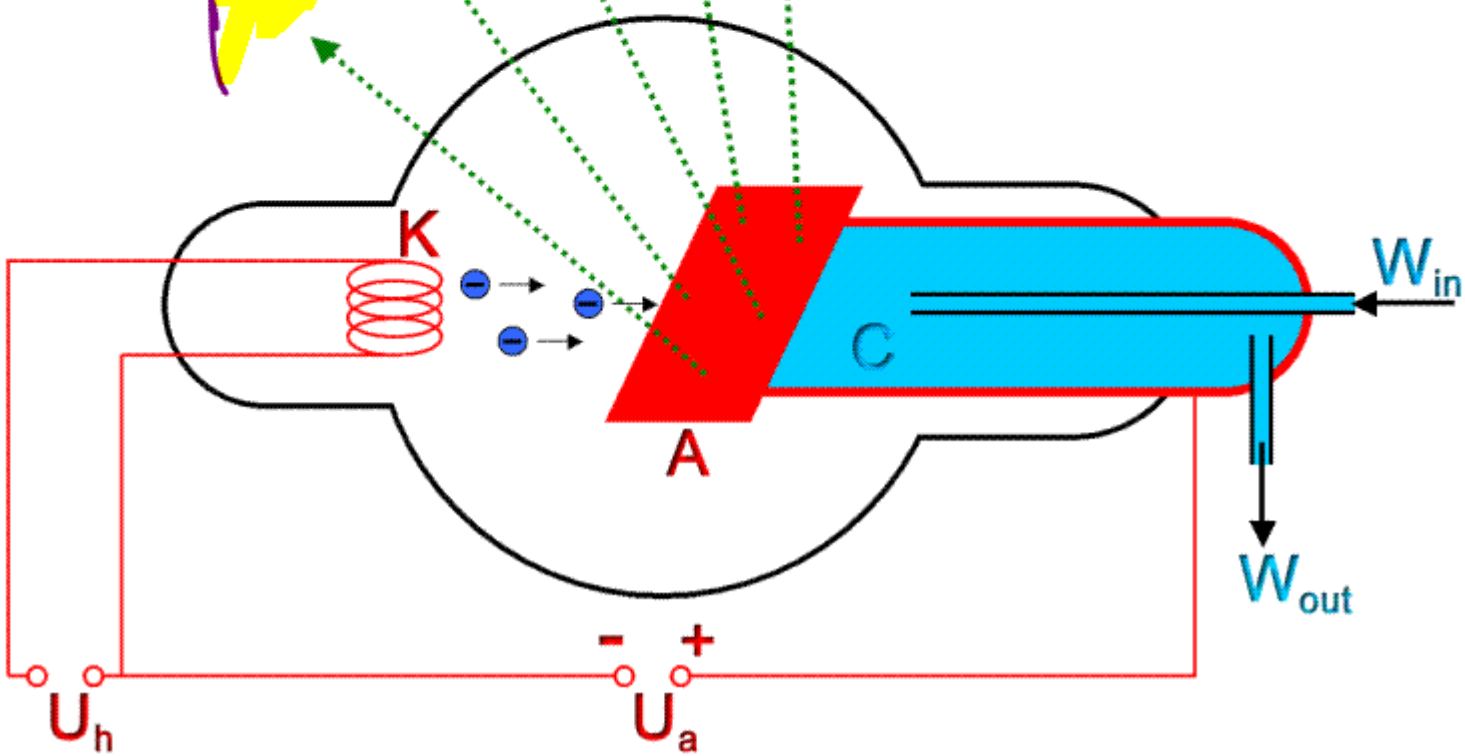


Visible light

$E = h\nu \sim$ few eV

$\lambda \sim 500$ nanometers $\sim 10^{-6} - 10^{-7}$ m

Cathode rays
→ electron beam
hits metal plate
X-rays emitted



Wilhelm Röntgen
(1845 - 1923)
Prussia → German

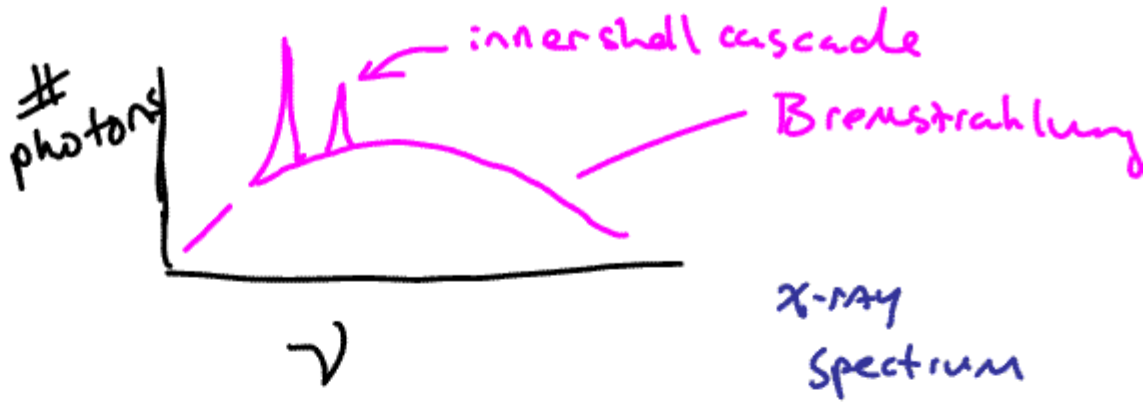
Generally given credit
for discovery of x-rays

Nobel Prize 1901

[1st Nobel Prize in physics]

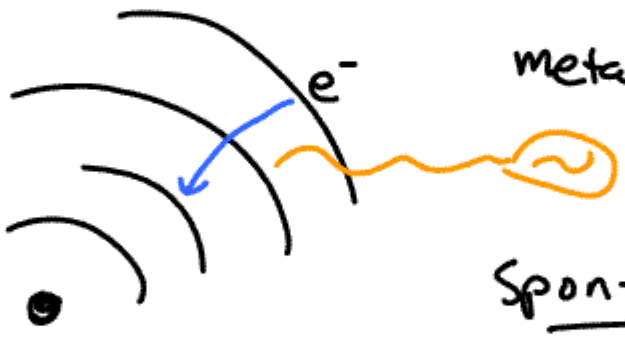
"In recognition of the extraordinary services
he has rendered by the discovery of the remarkable rays"

... not accidental and many
others working on cathode ray
tubes. independent discoveries
Ivan Pulyui, Fernando Sanford, Crookes,
Hertz, Tesla, etc.

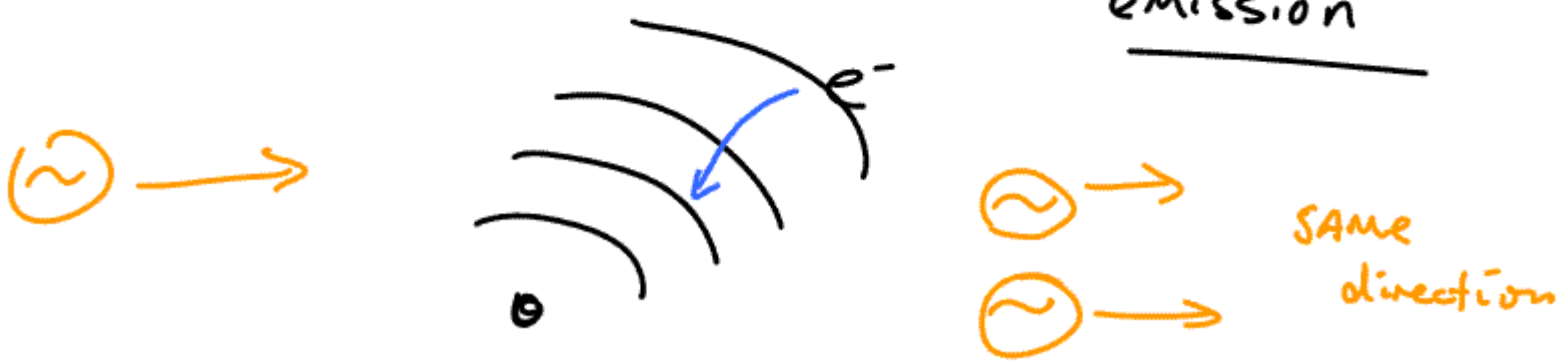


LASERS

Einstein



Spontaneous emission



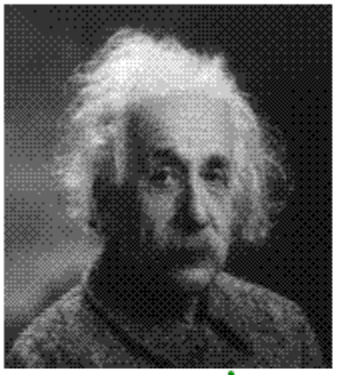
Stimulated emission

The Laser

Some of the players

Light **A**mplification by the **S**timulated **E**mission of **R**adiation

↳ Gordon Gould, 1957



Einstein – Theory of Stimulated and Spontaneous Emission

1964 Nobel Prize

Nicolay Basov

Alexandr Prokhorov

Charles Townes

1981 Nobel Prize

Arthur Schawlow

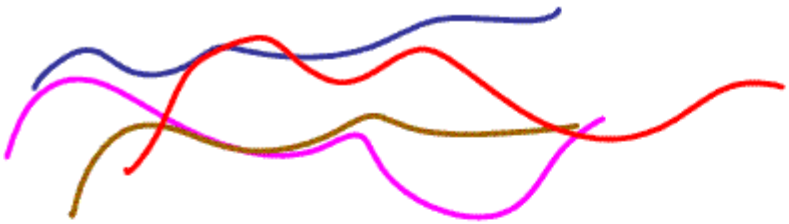
Theodore Maiman

→ 1st operable laser

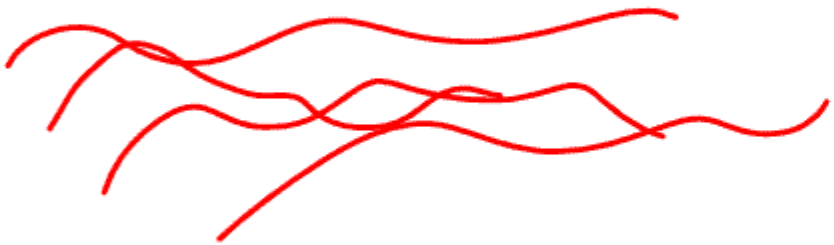
LASER

1 atoms in gnd STATE
2 Pump them
↳ Metastable
3 Population inversion
Most Atom in
Metastable
excited STATE

4 spontaneous
Decay
5 Stimulated
emission
6 gain



White light
random phases
and colors



Monochromatic
light
random phases

Coherent light

Monochromatic
and in phase