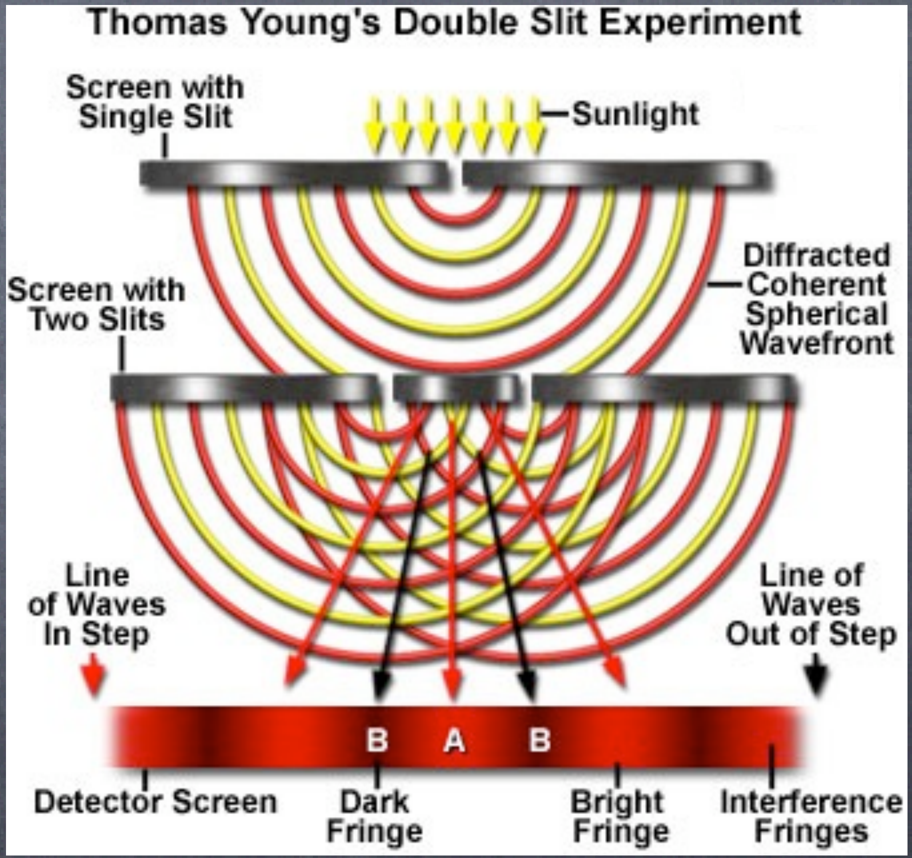
Chapter 6: Quantum Mechanics

Sidney Coleman

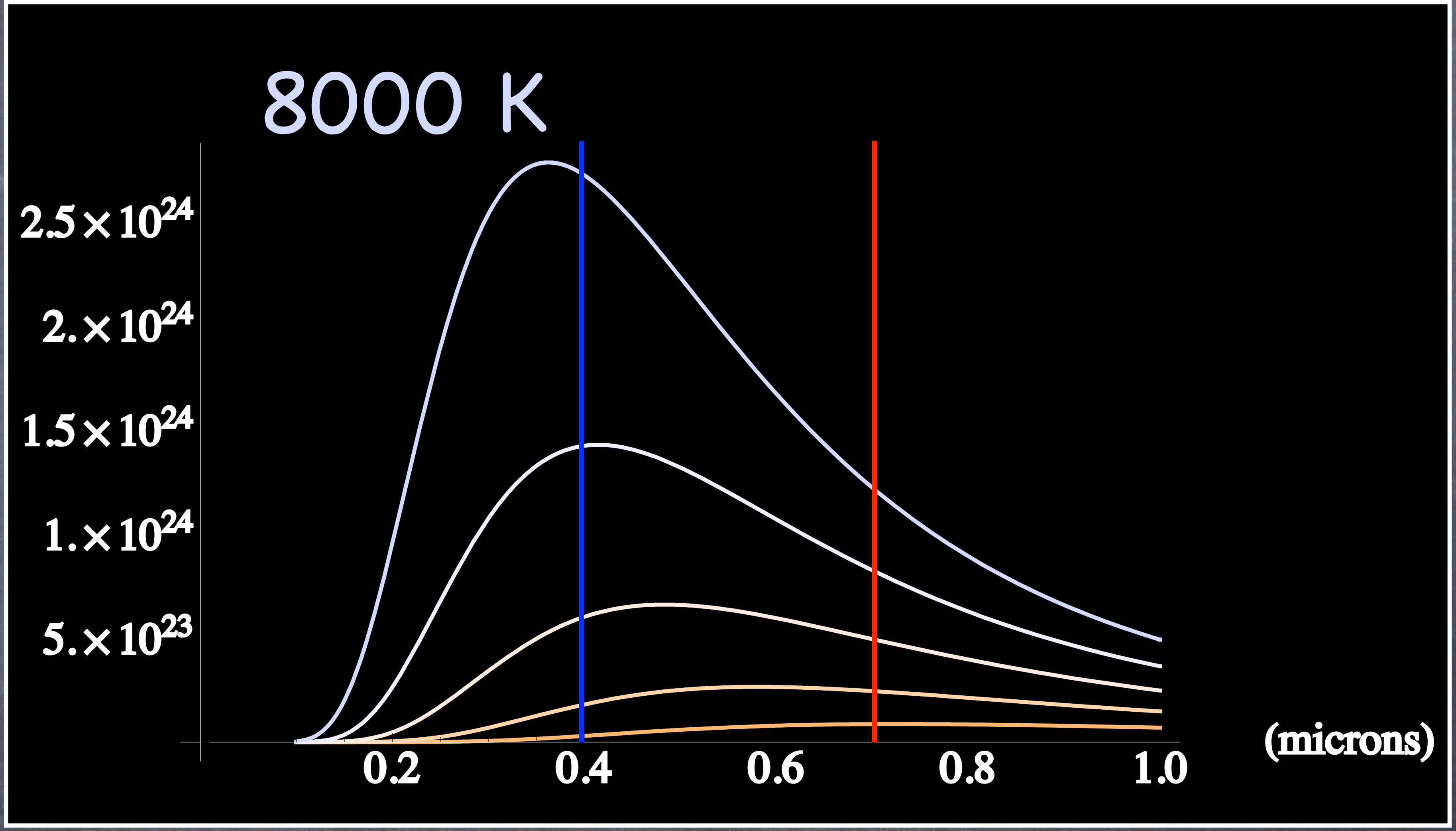
Quantum Wierdness

Young's Double Slit



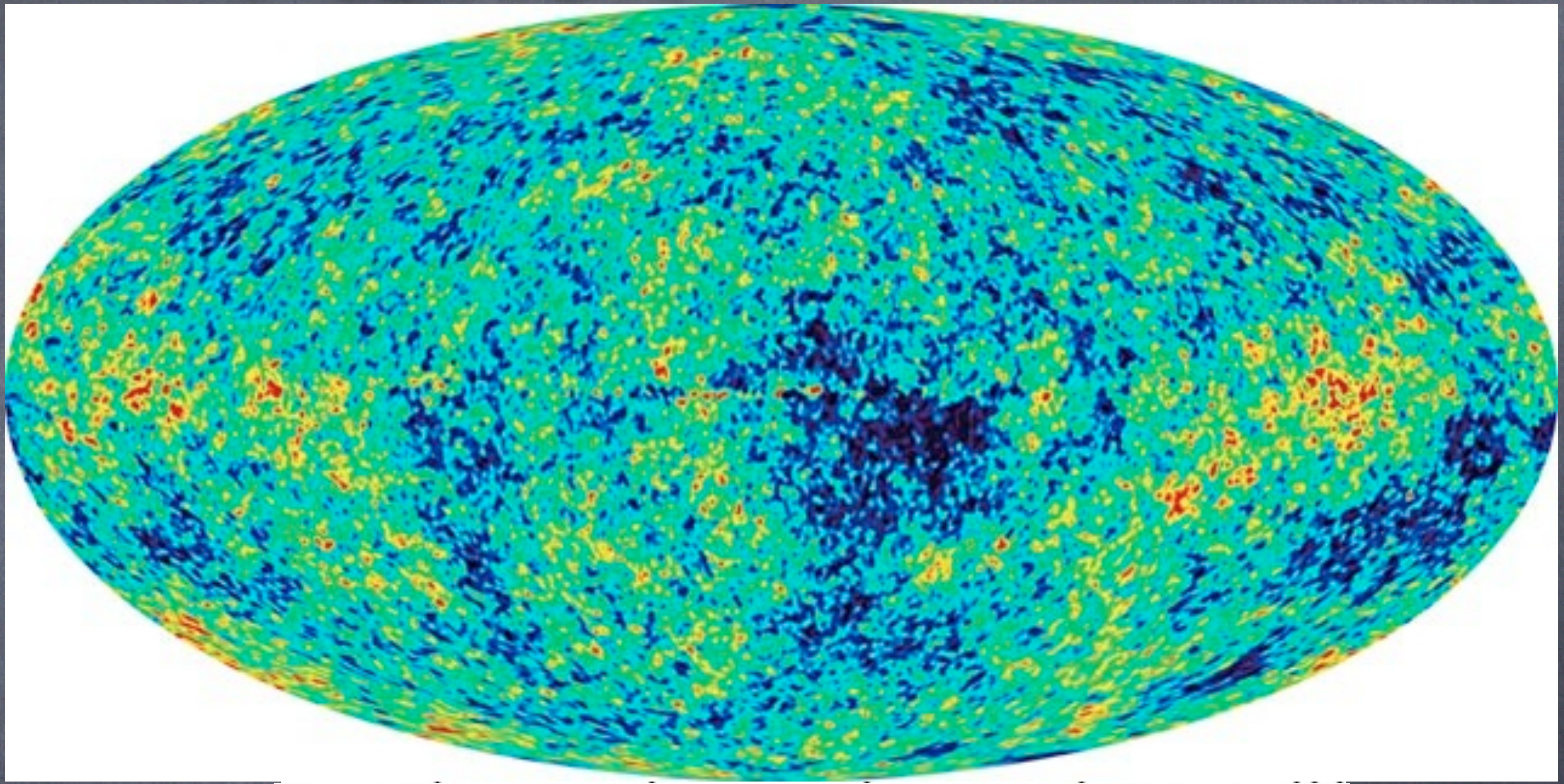
1801

Planck

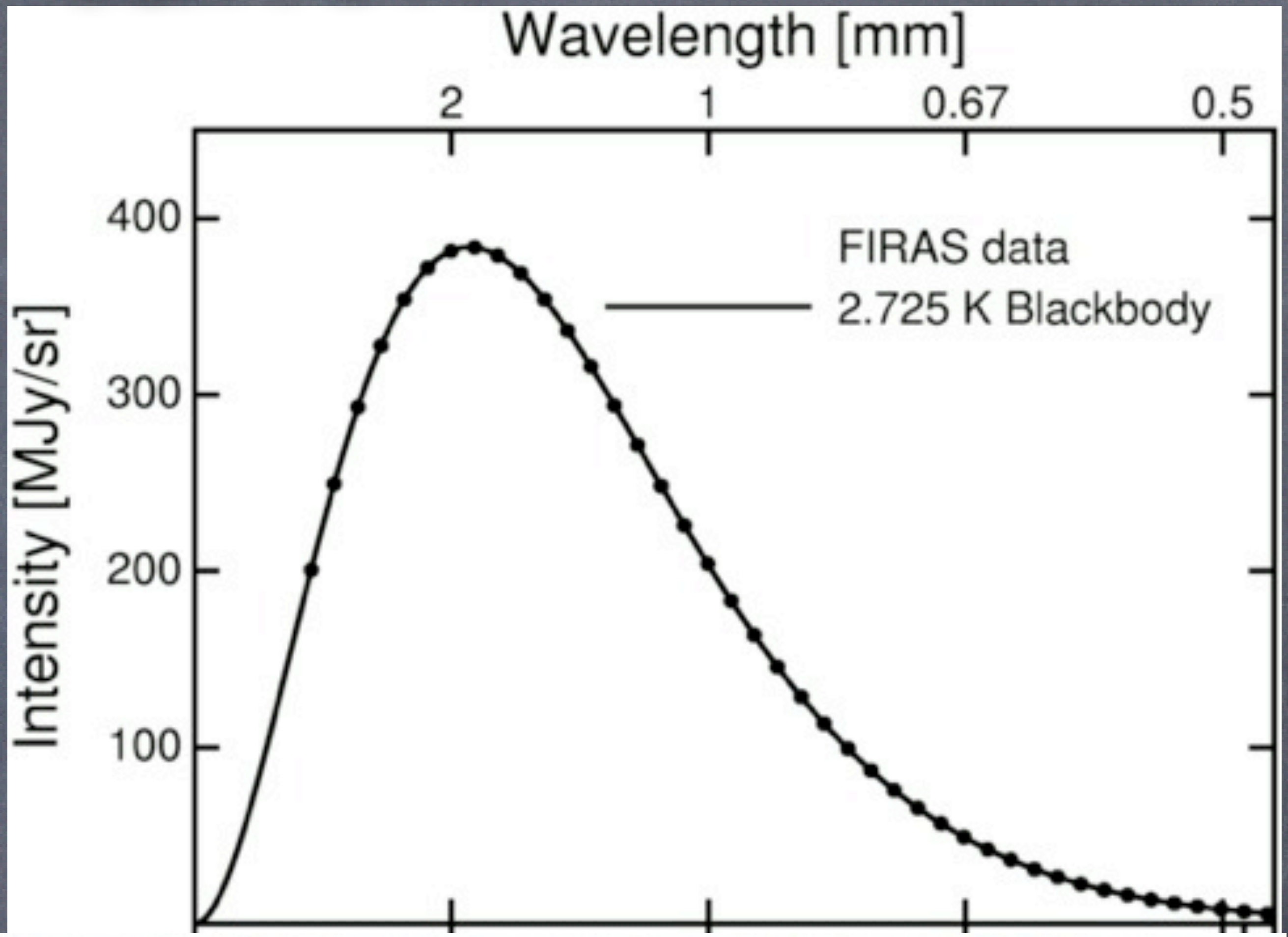


4000 K

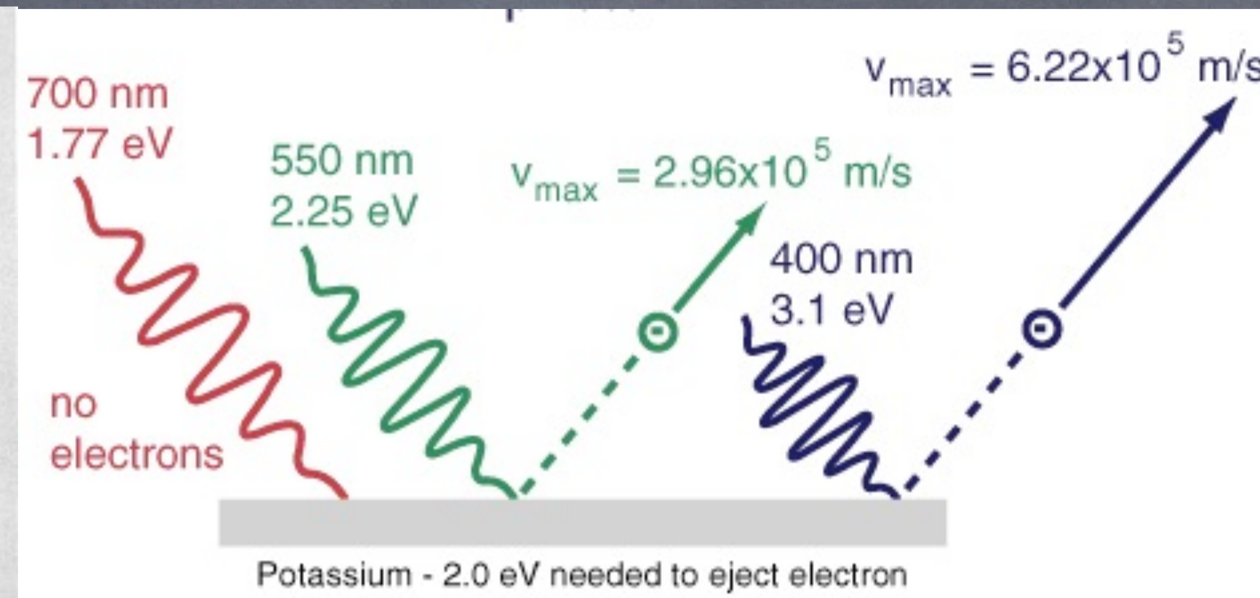
Planck



Planck


Wavelength [mm]
2
1
0.67
0.5
400
300
200
100
Intensity [MJy/sr]
FIRAS data
2.725 K Blackbody

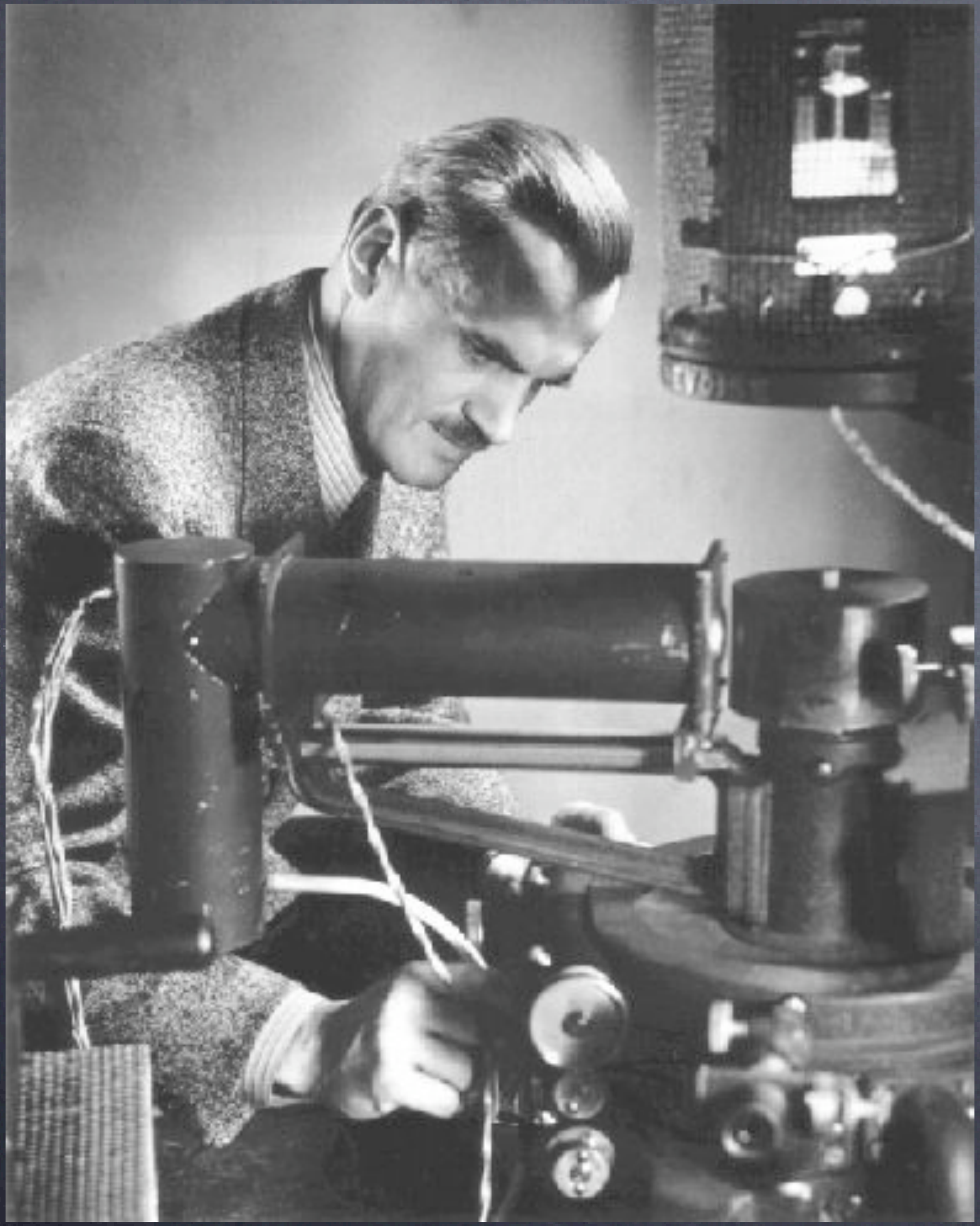
Einstein

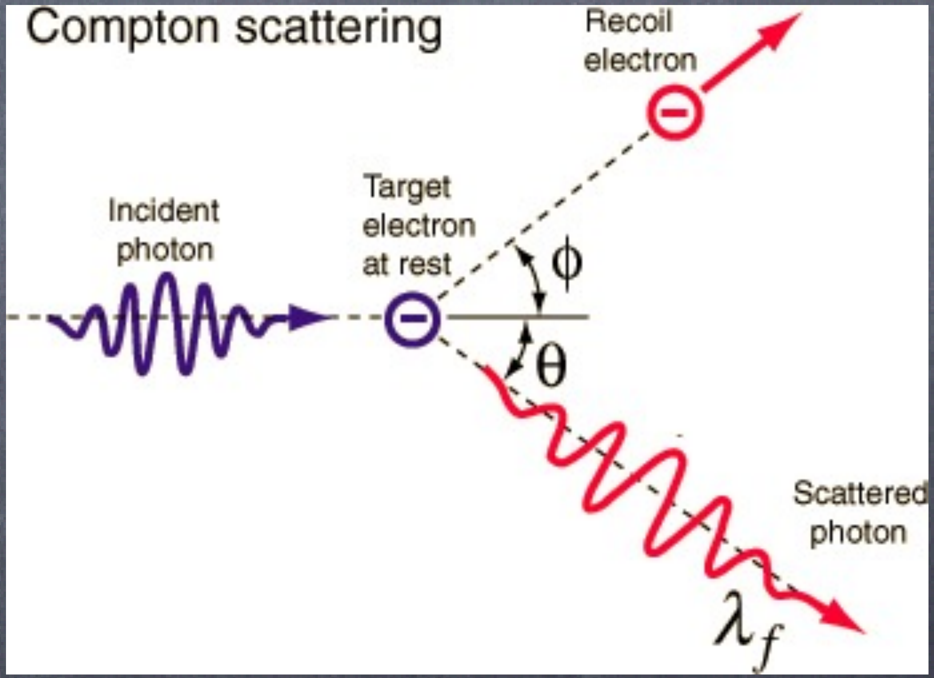


$$E = h\,f = \hbar\,2\pi f = \hbar\omega$$

Nobel Prize 1921

Compton



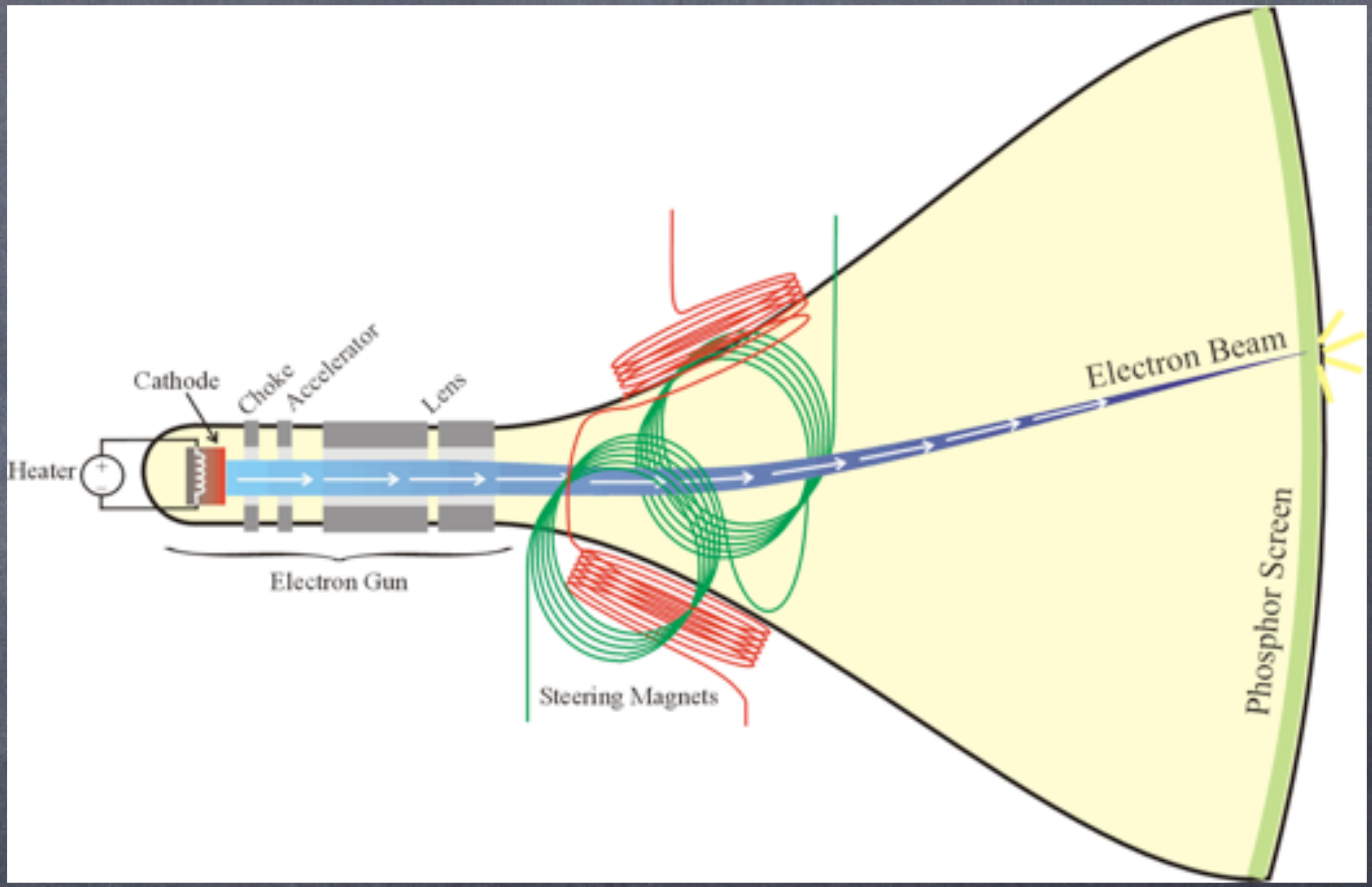


Compton scattering
Recoil electron
Incident photon
Target electron at rest
ϕ
θ
Scattered photon
λ_f

J.J. Thomson

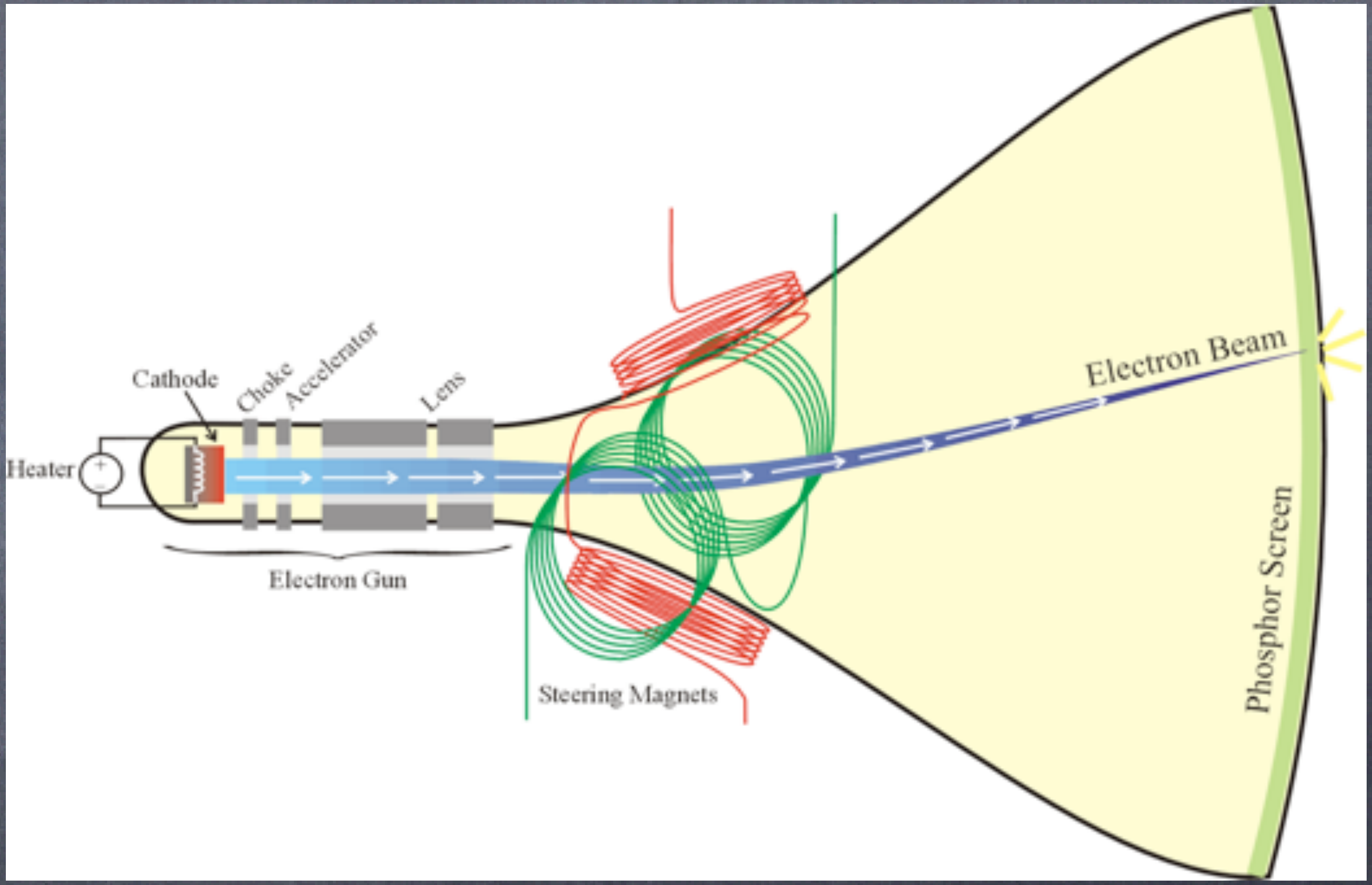
J.J. Thomson

J.J. Thomson

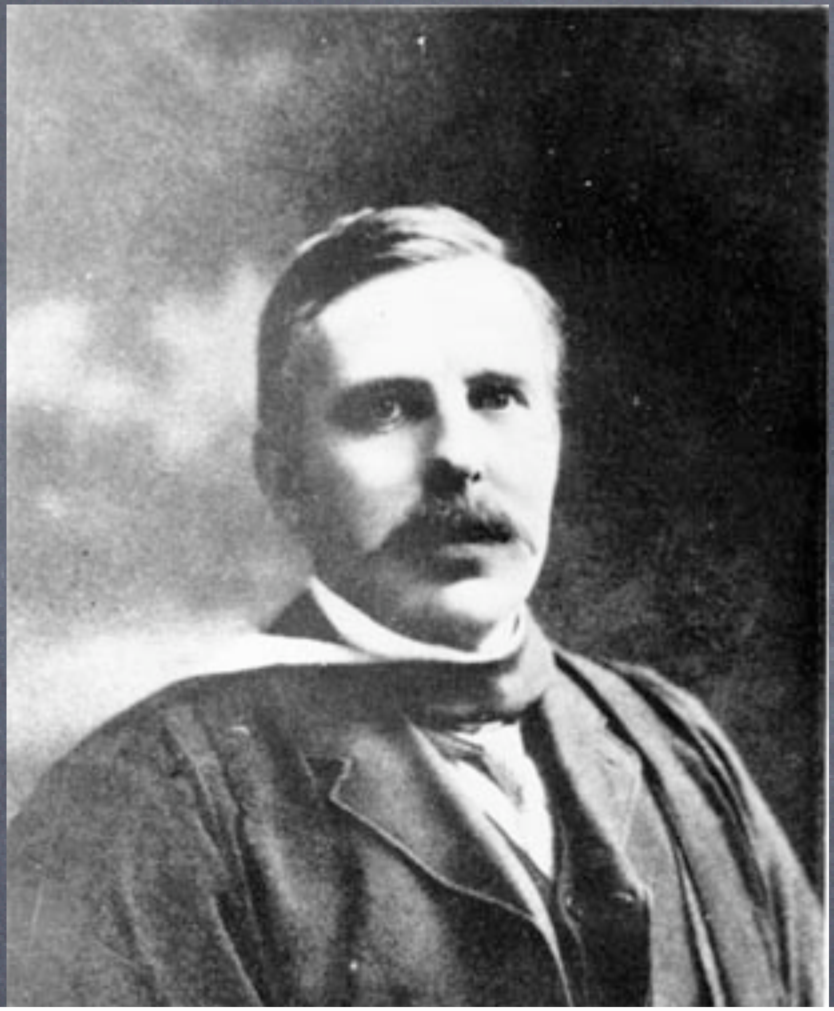


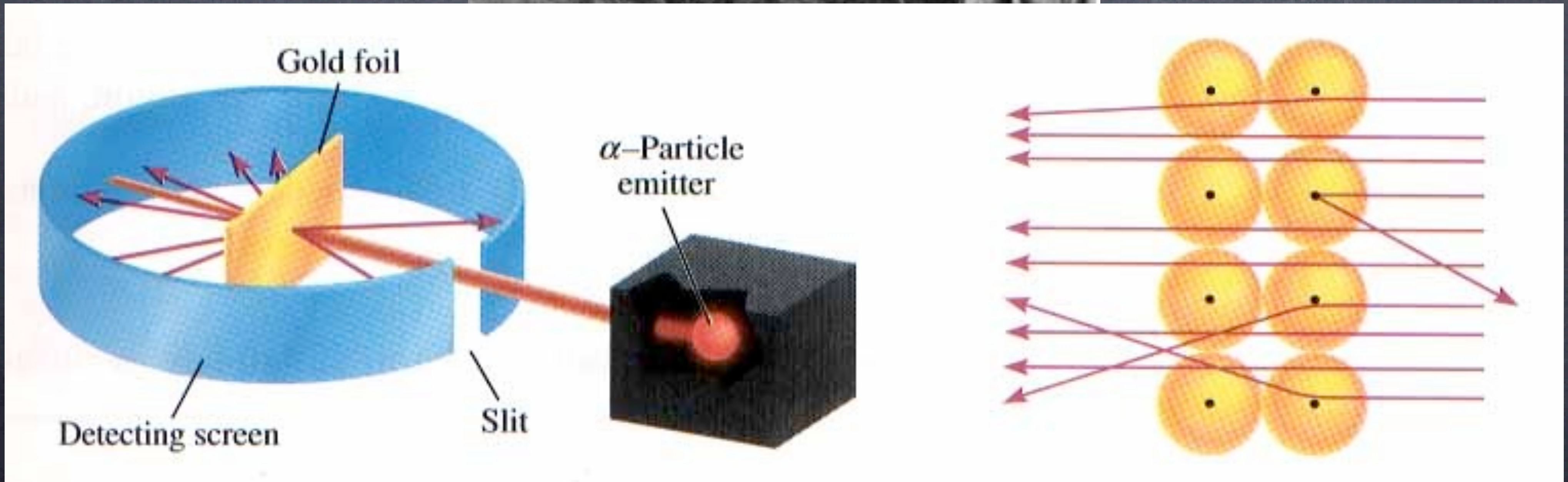
Cathode
Choke
Accelerator
Lens
Heater
Electron Gun
Steering Magnets
Electron Beam
Phosphor Screen

J.J. Thomson

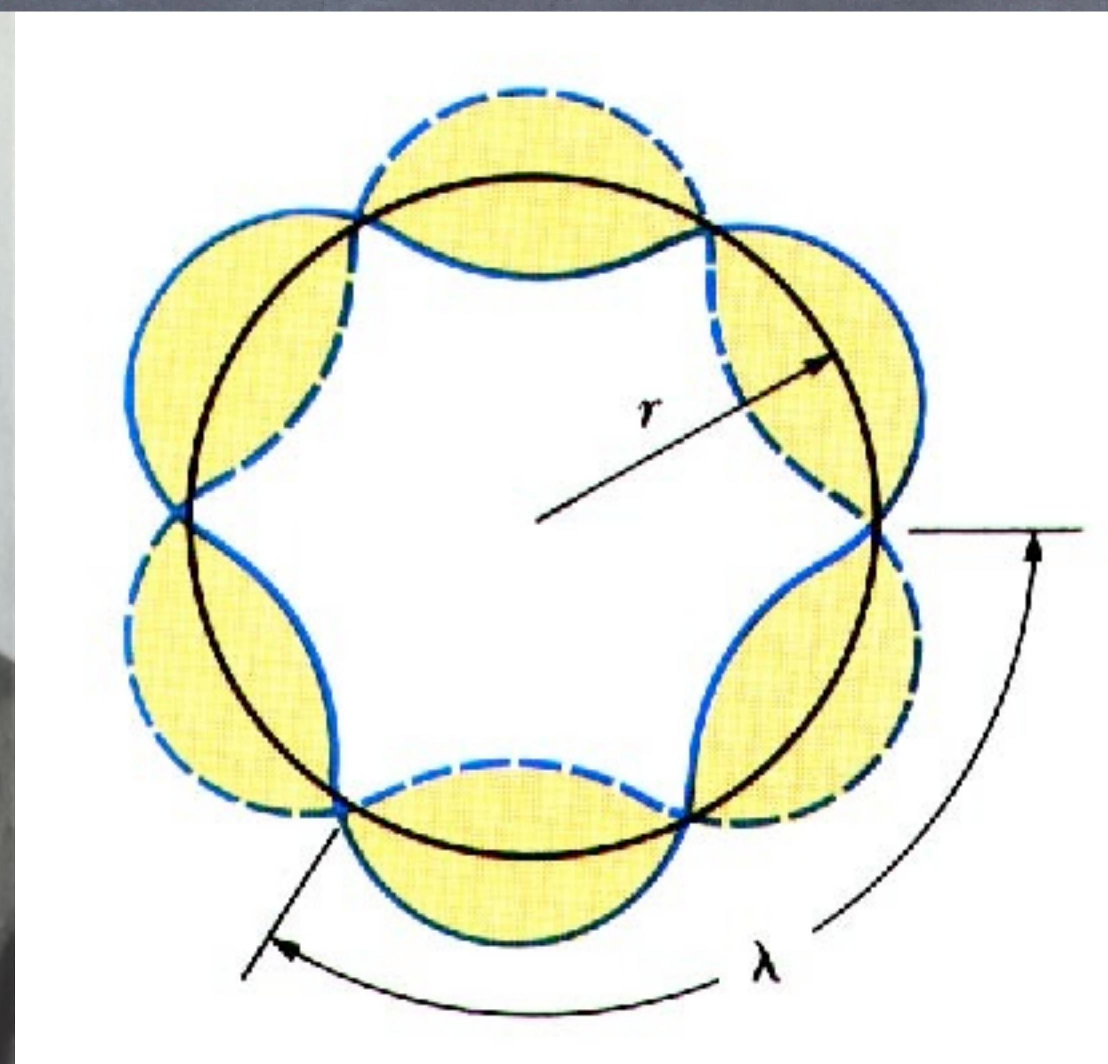

Cathode
Choke
Accelerator
Lens
Heater
Electron Gun
Steering Magnets
Electron Beam
Phosphor Screen

Rutherford

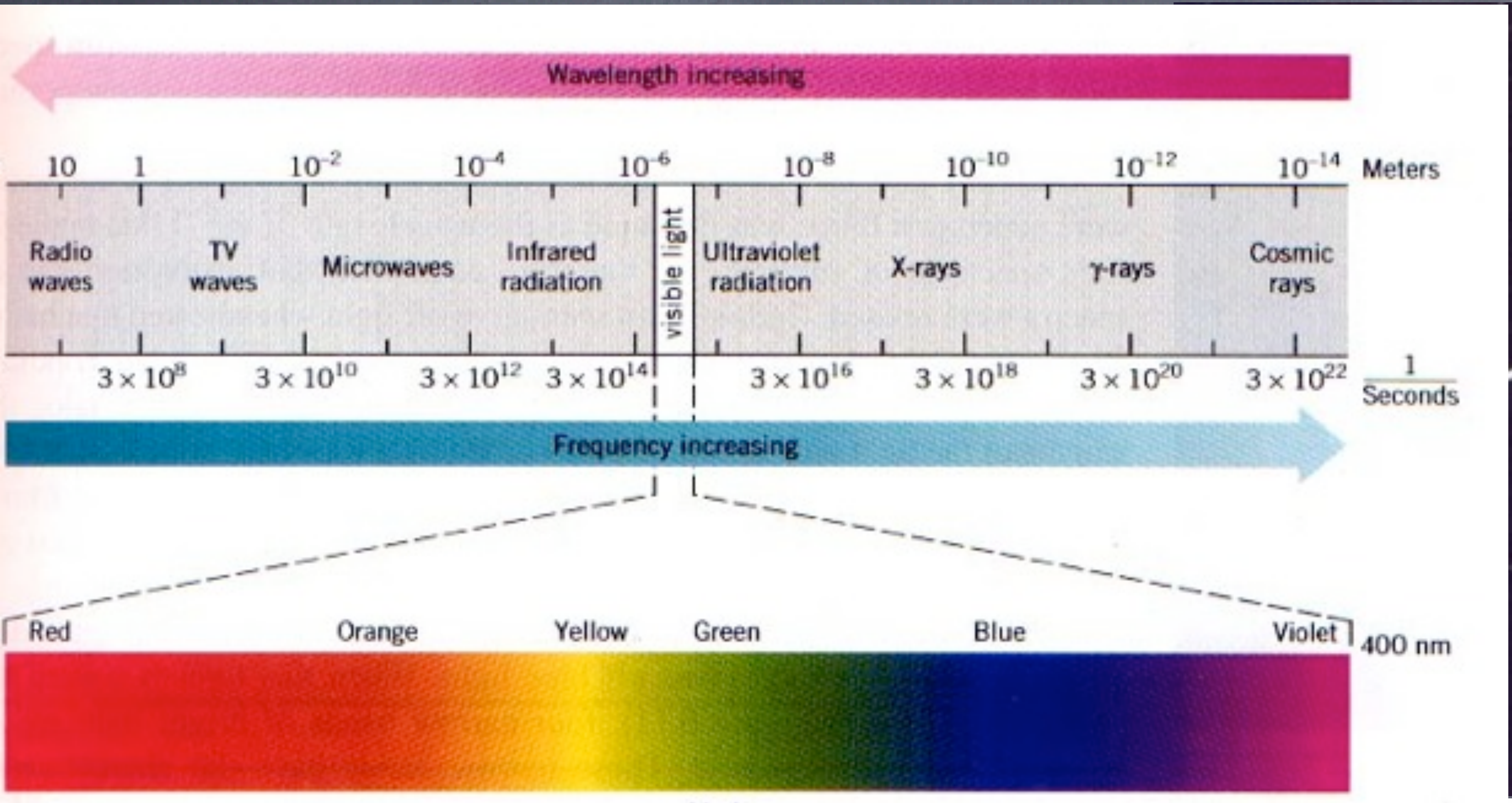


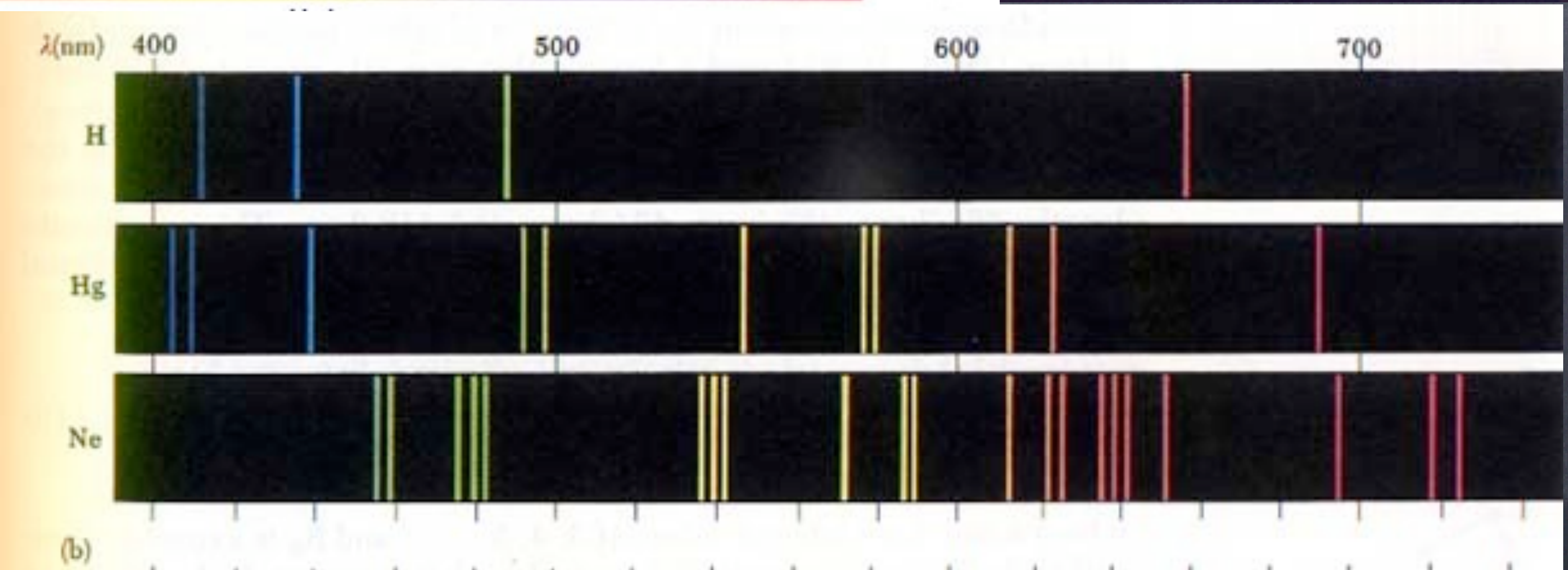


Bohr and de Broglie

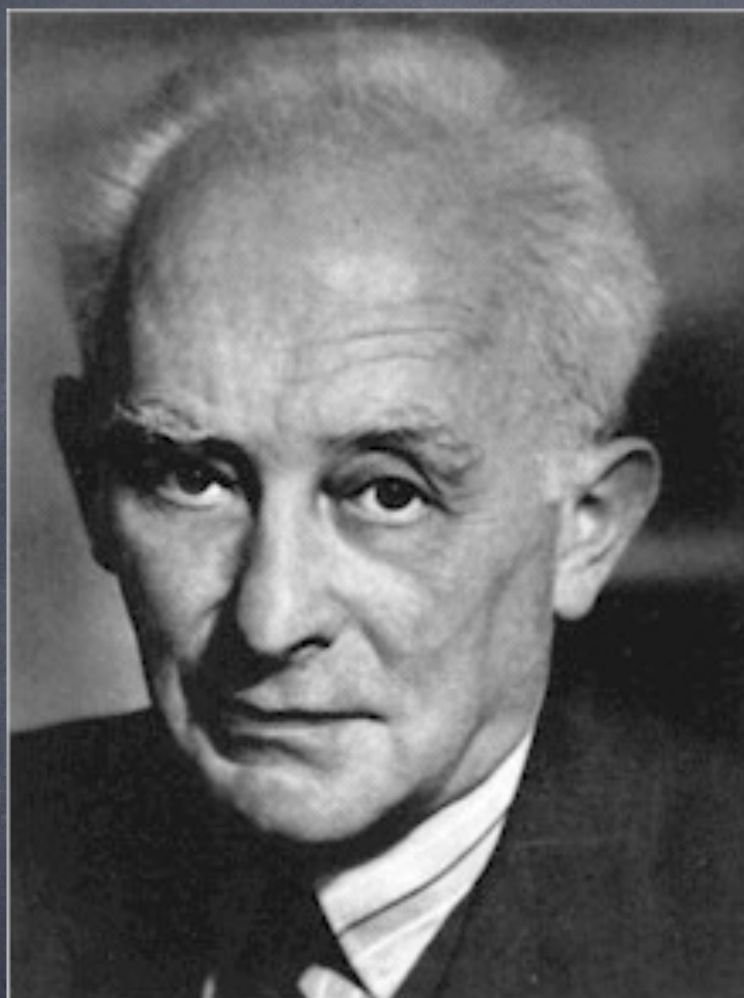


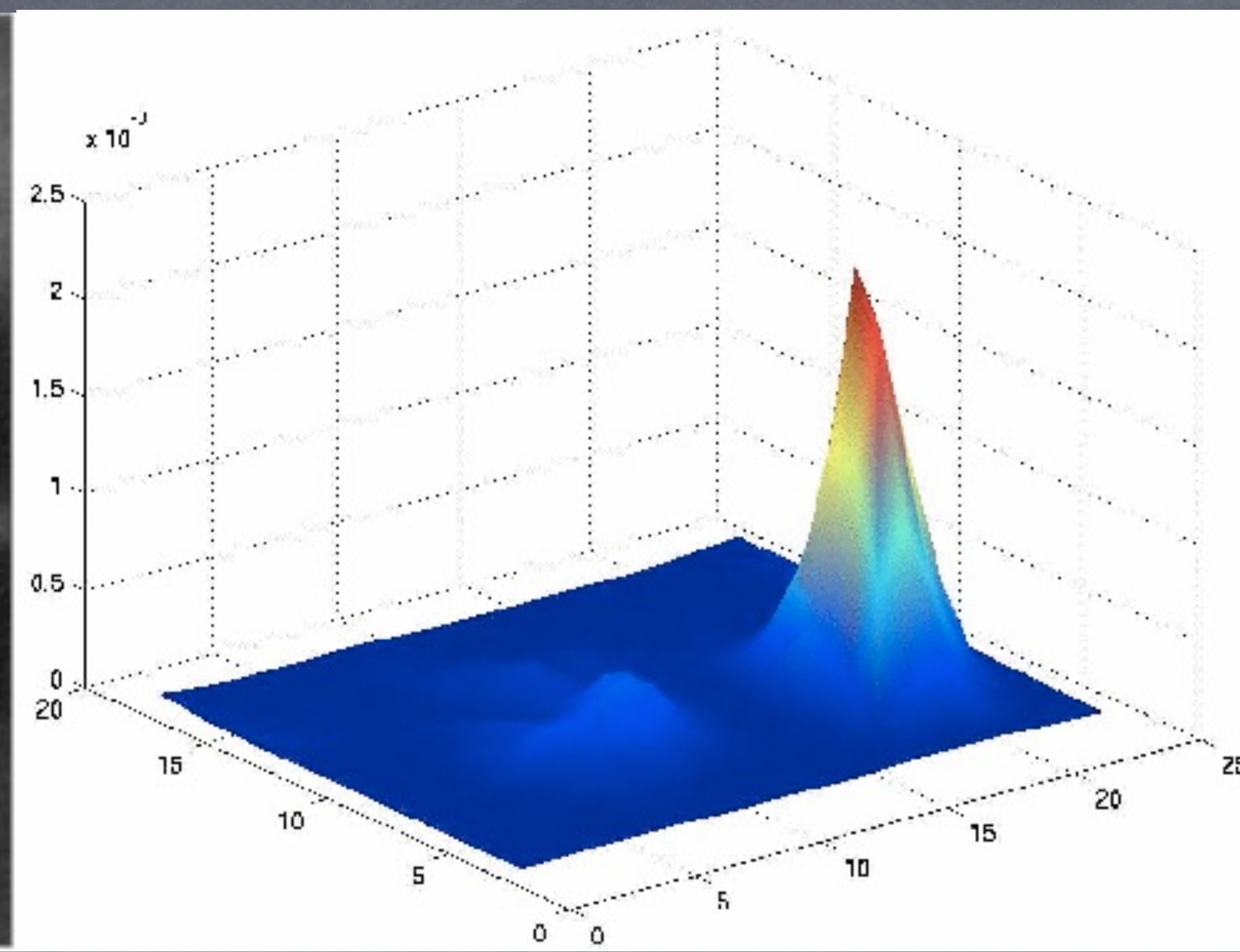
Spectra


Wavelength increasing
10
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
Meters
Radio waves
TV waves
Microwaves
Infrared radiation
visible light
Ultraviolet radiation
X-rays
γ-rays
Cosmic rays
3×10^{8}
3×10^{10}
3×10^{12}
3×10^{14}
3×10^{16}
3×10^{18}
3×10^{20}
3×10^{22}
$\frac{1}{\text{Seconds}}$
Frequency increasing
Red
Orange
Yellow
Green
Blue
Violet
400 nm


λ(nm)
400
500
600
700
H
Hg
Ne
(b)

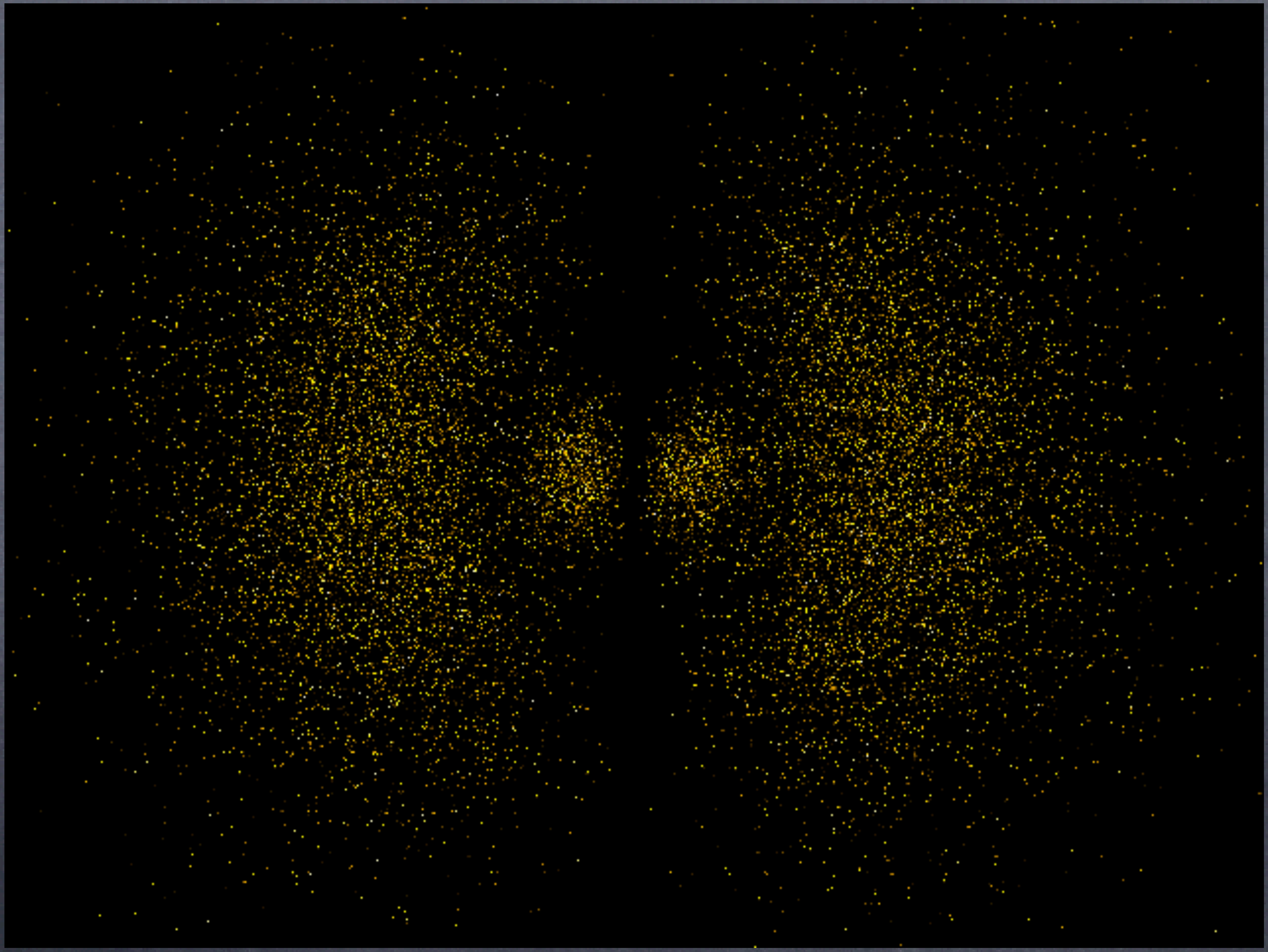
Born



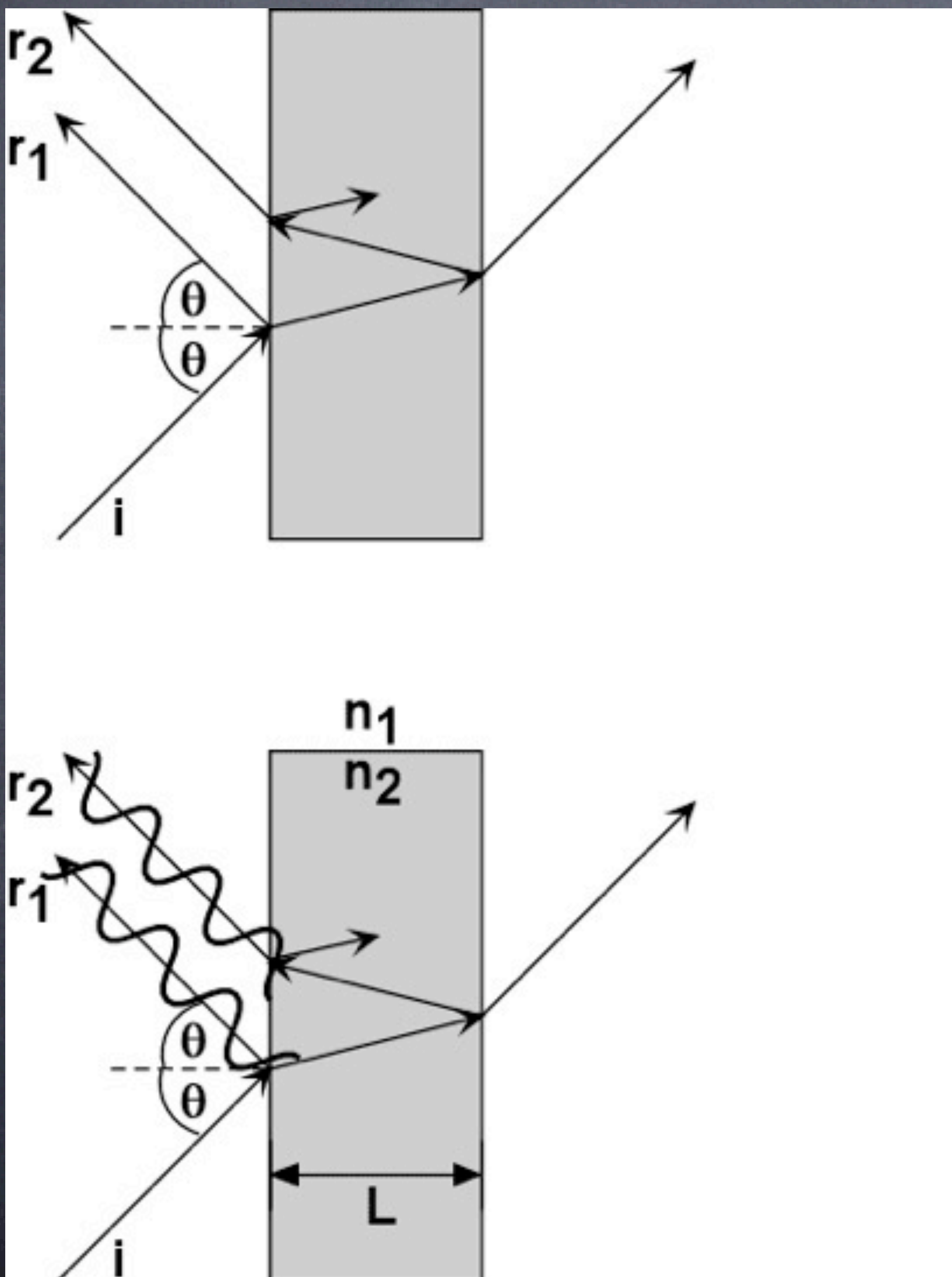


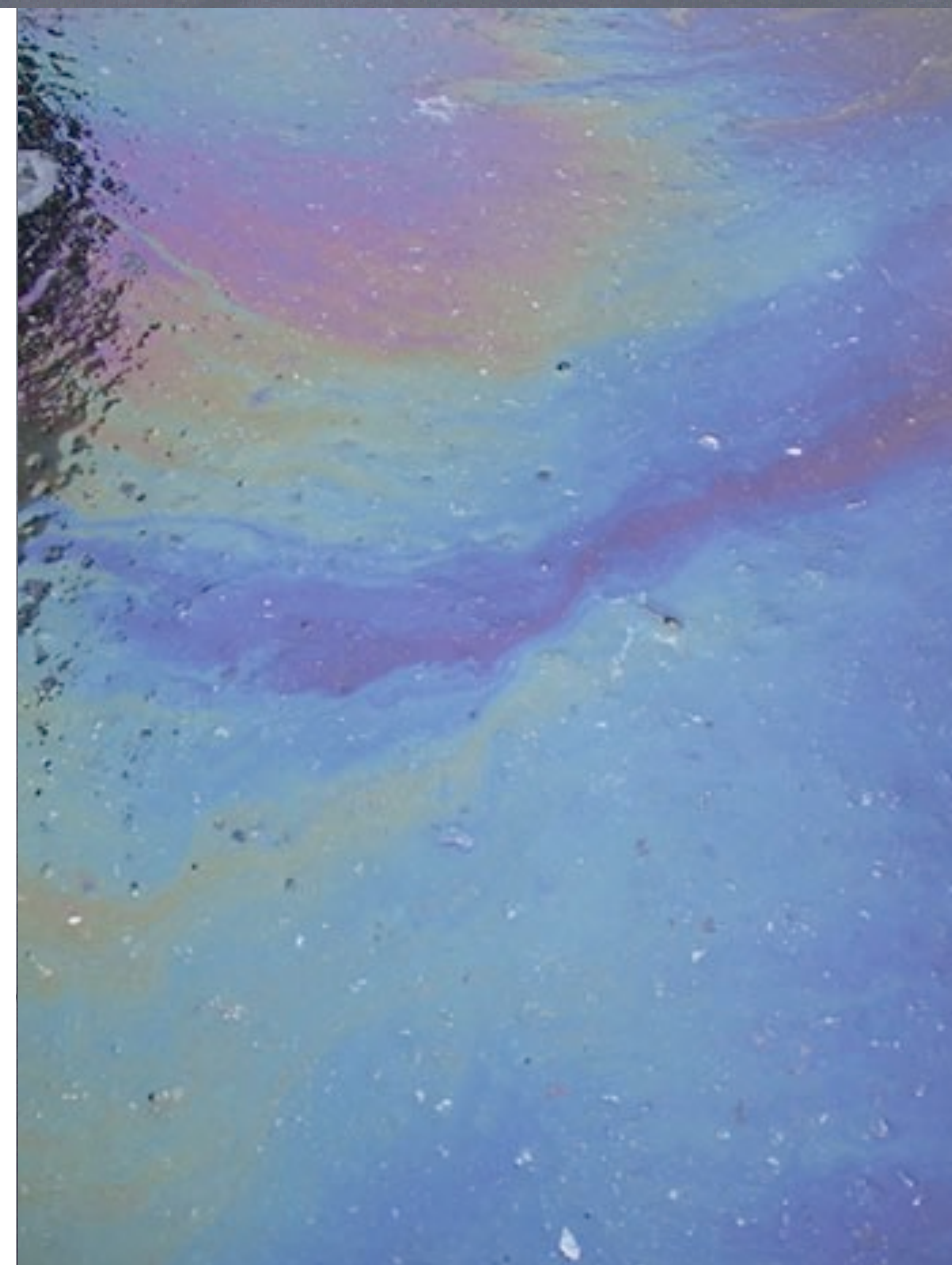
probability waves

Electron Wavefunctions

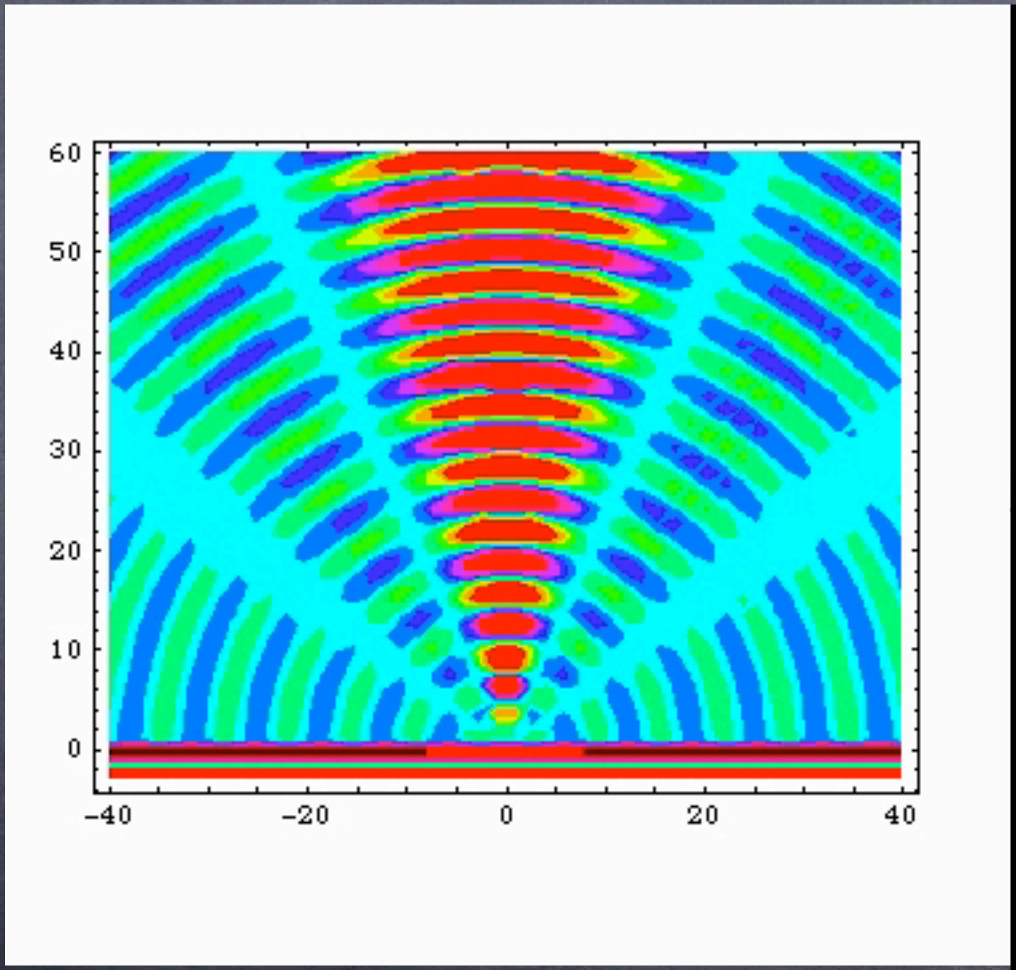


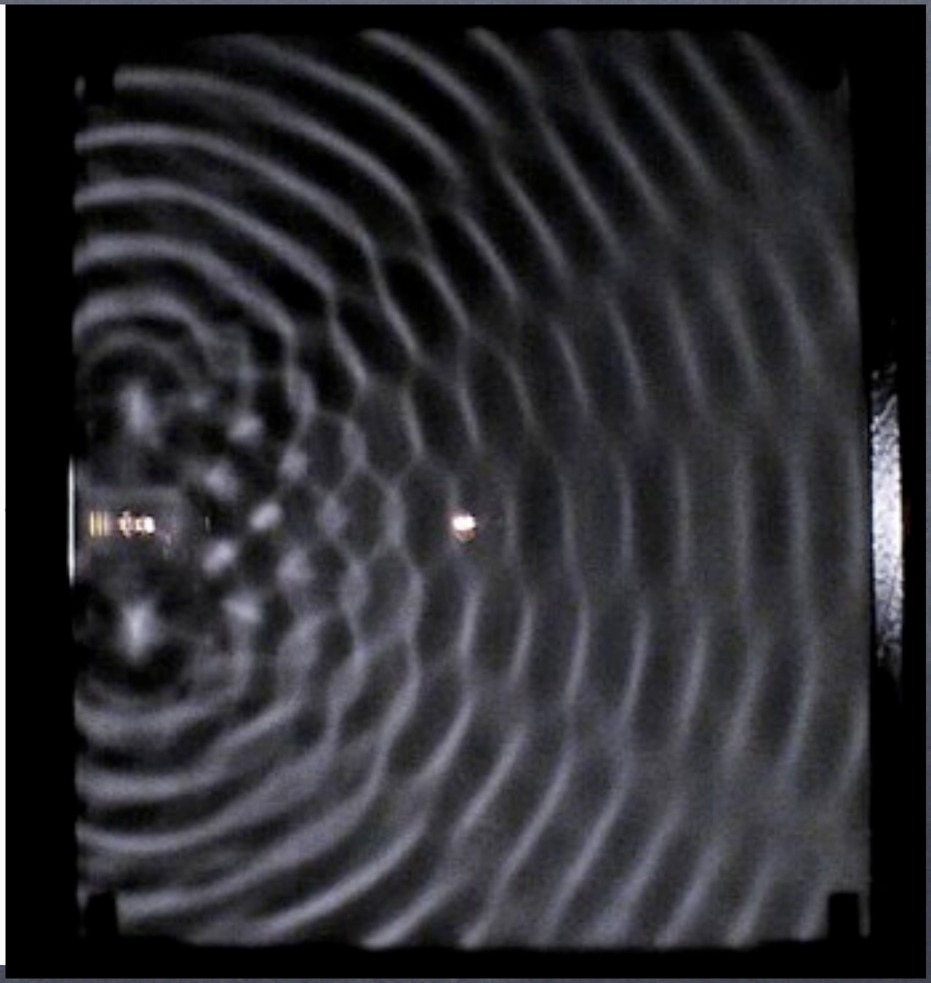
Light Waves Interfere



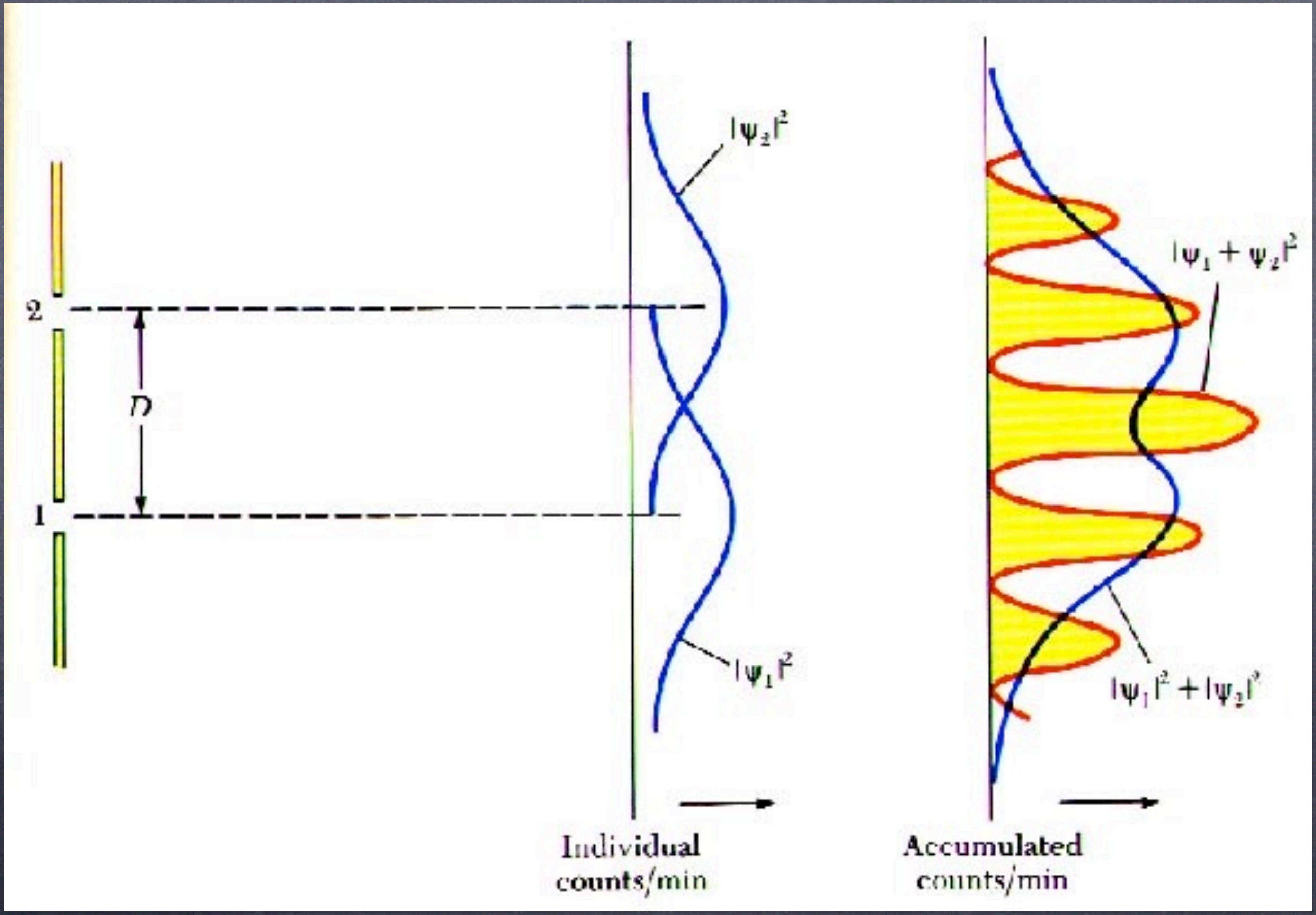


Interference

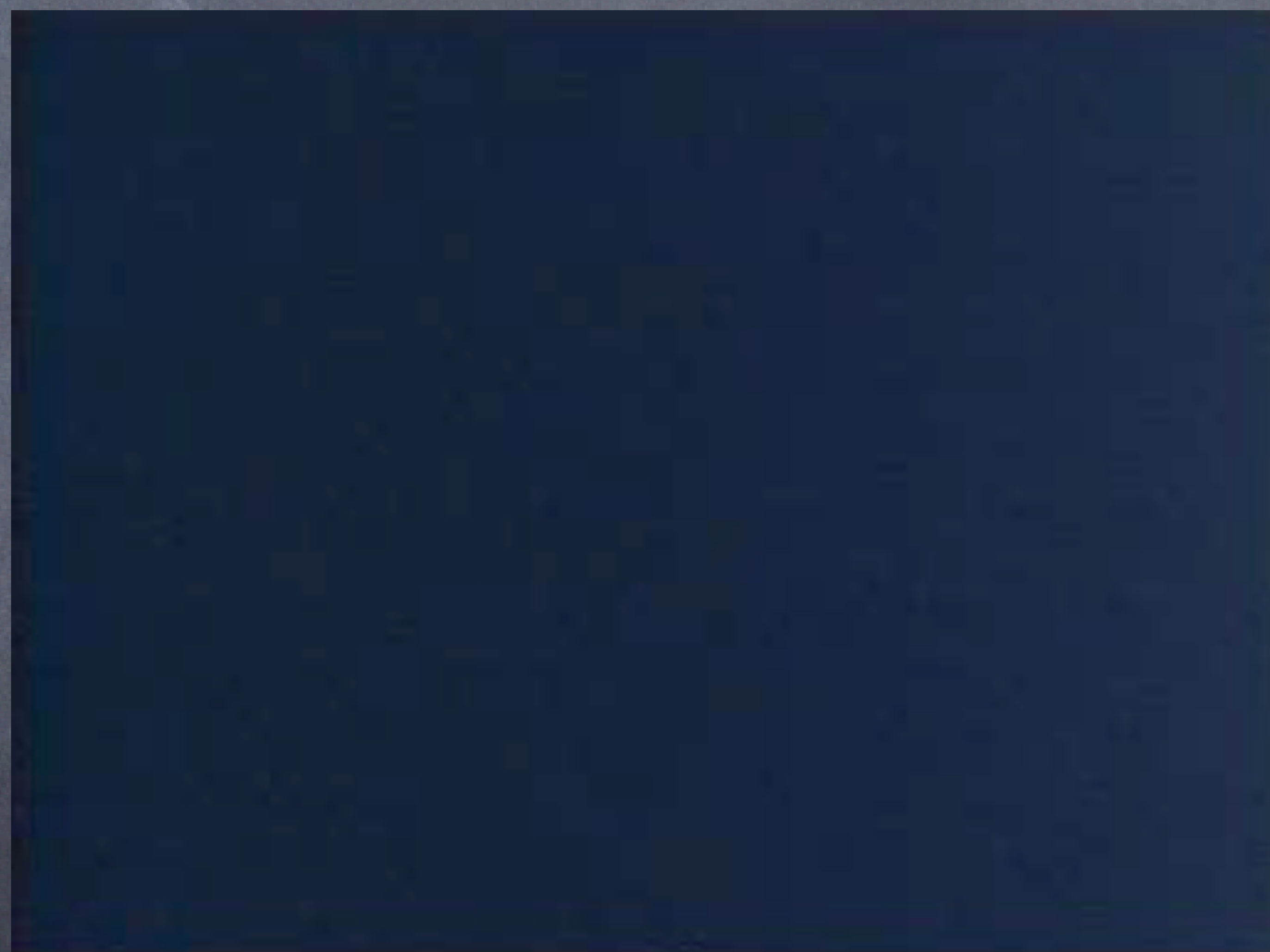




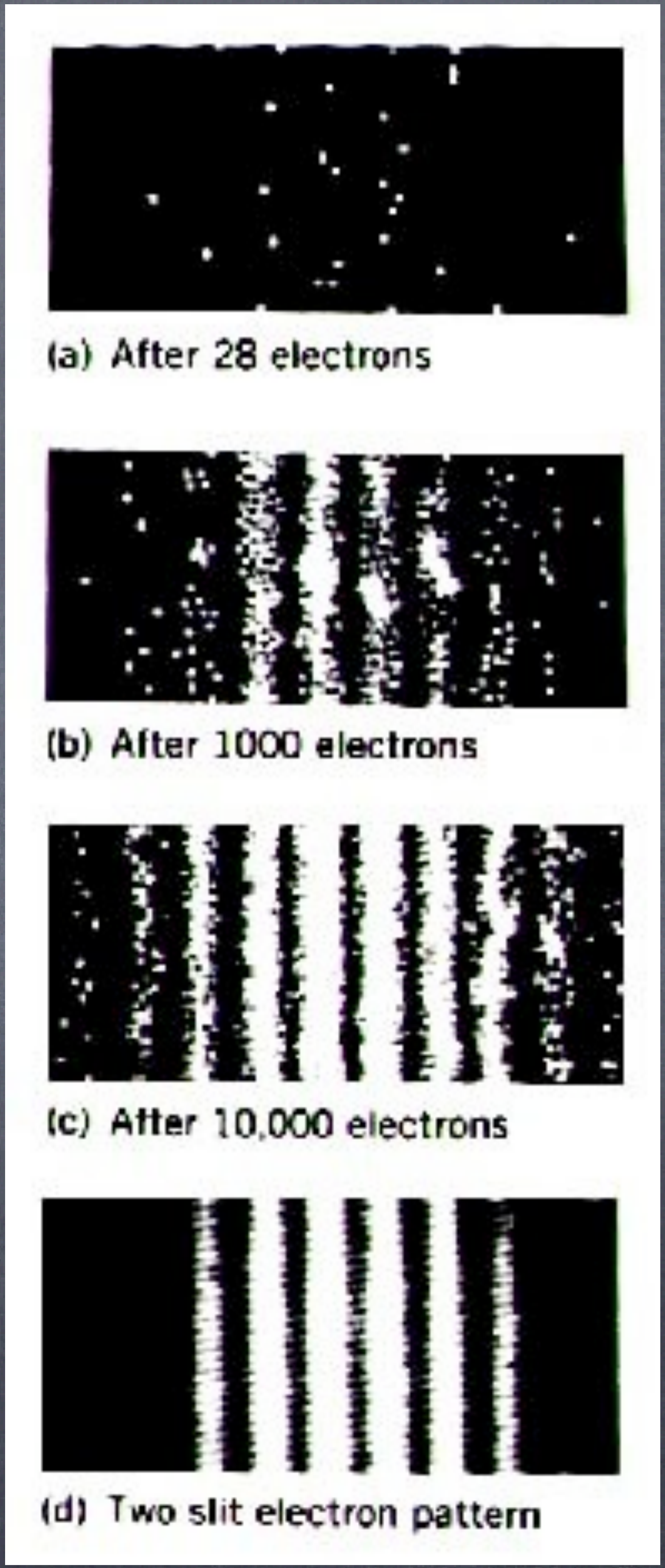
Probability Waves



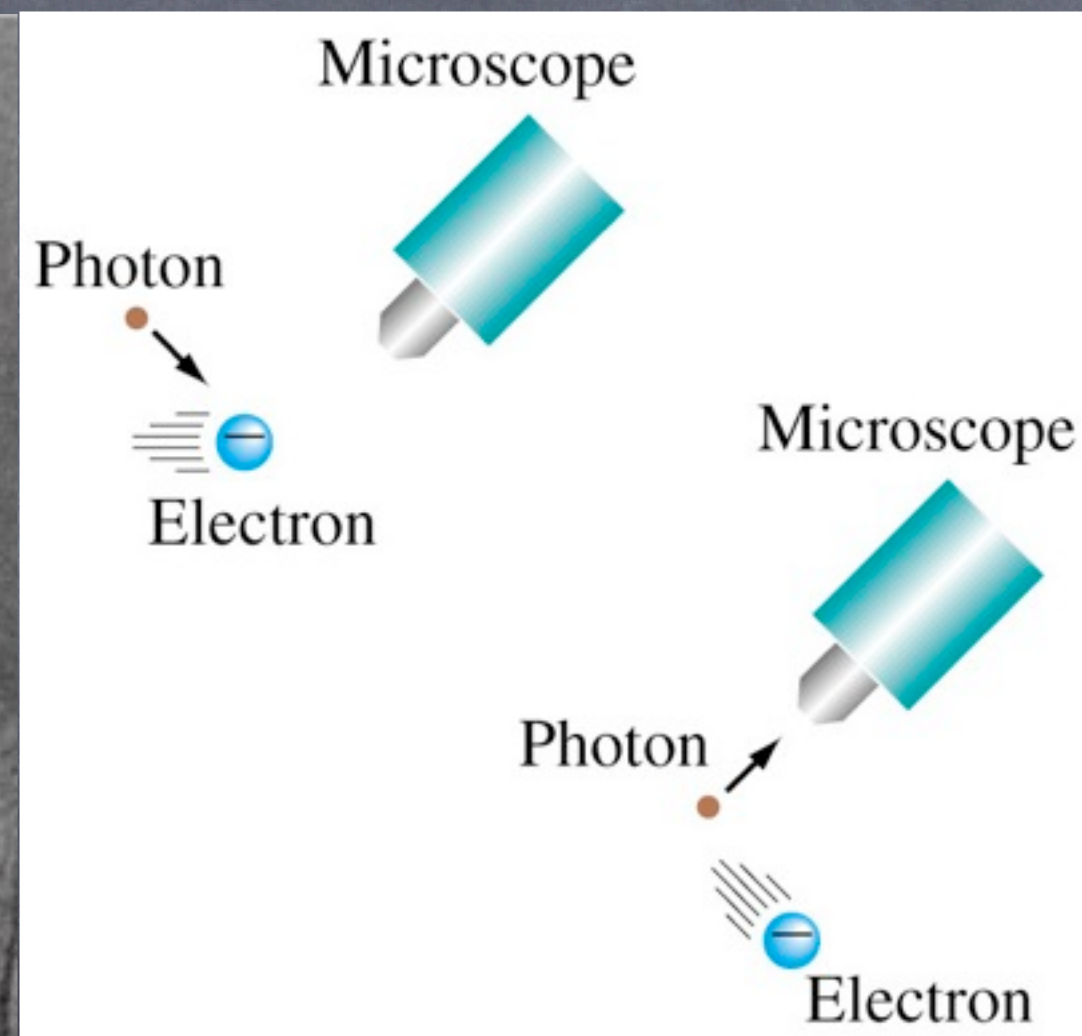
Electron Double Slit



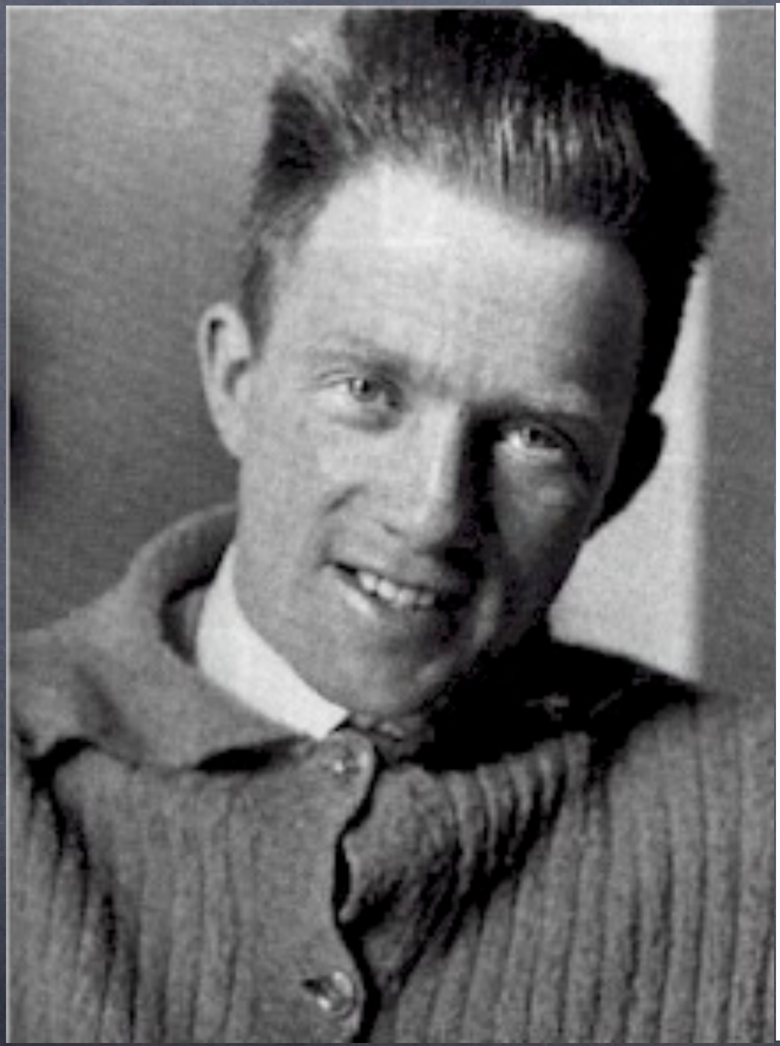
Electron Double Slit

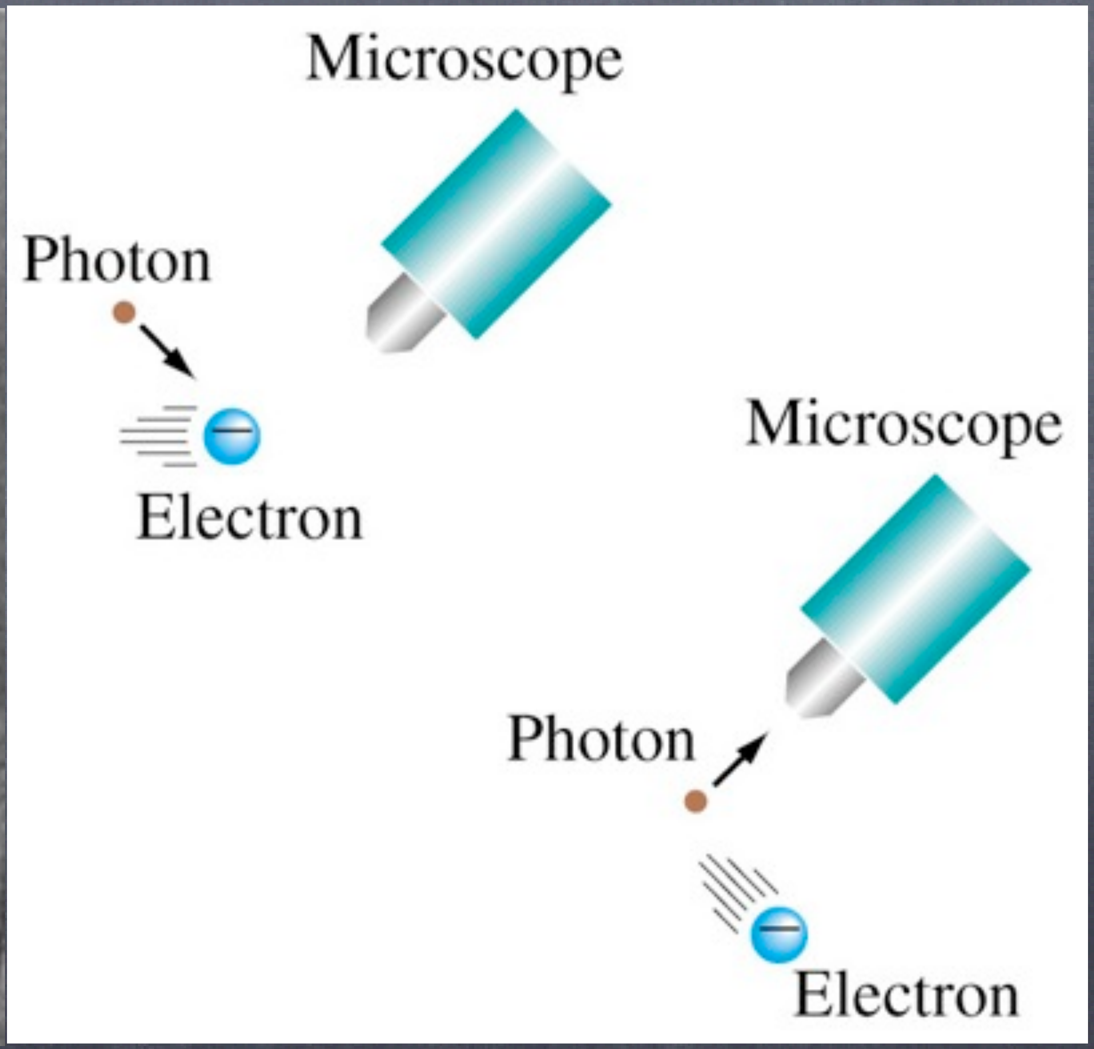


Heisenberg's Uncertainty Principle

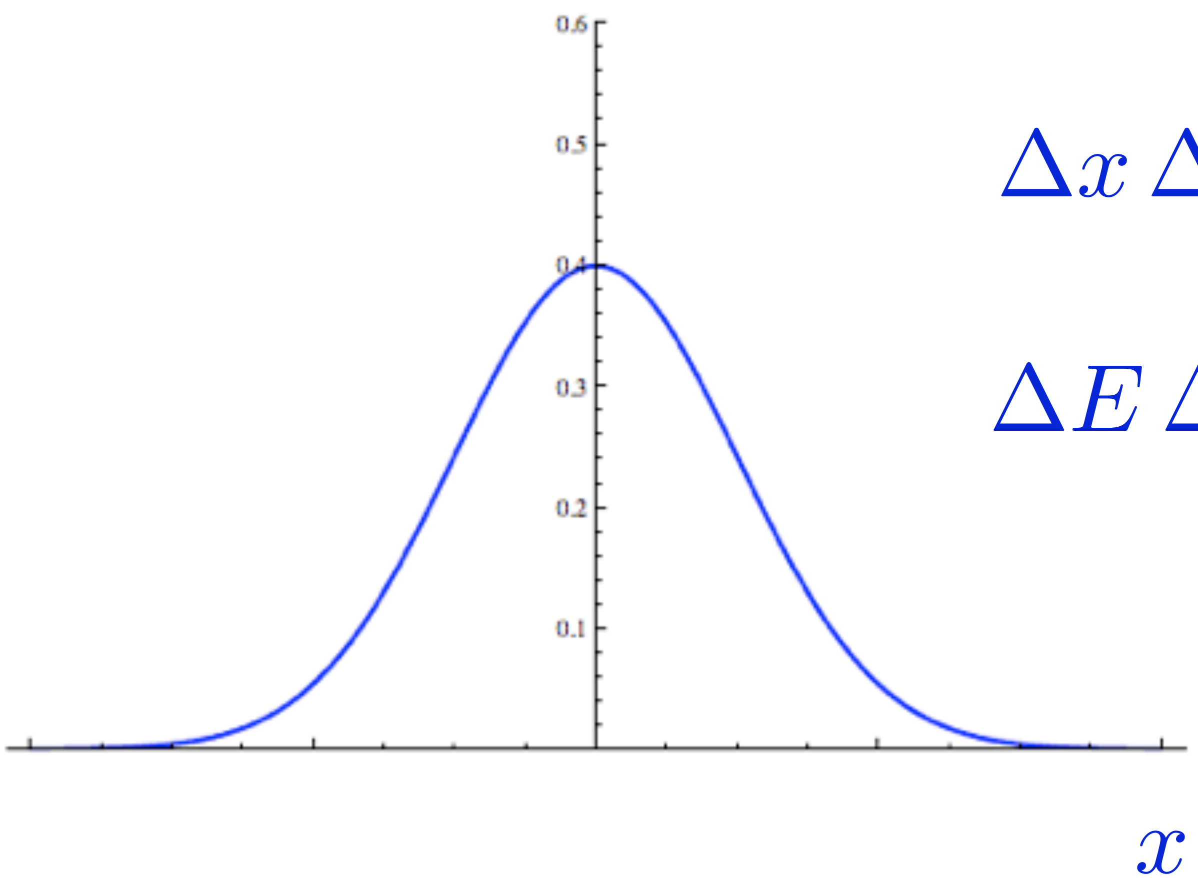


Heisenberg's Uncertainty Principle



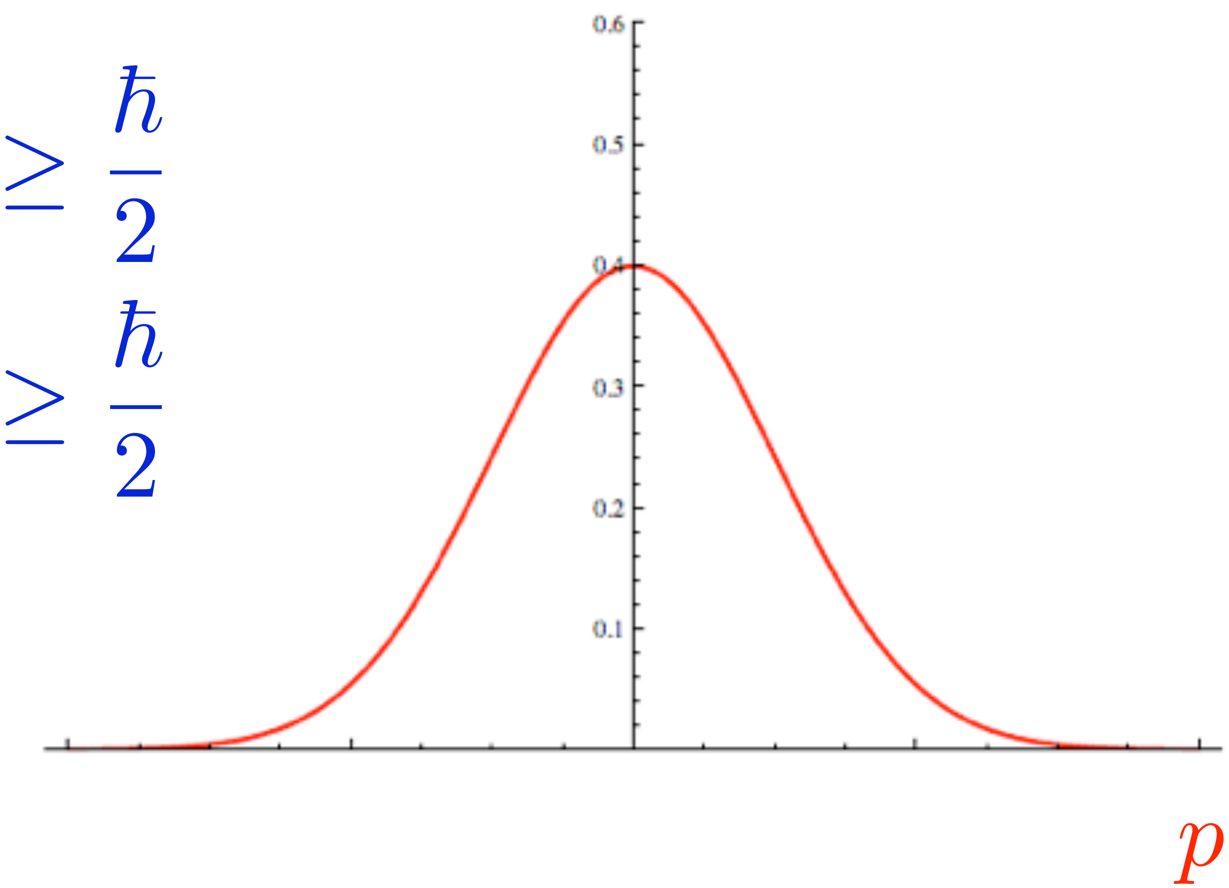


Uncertainty Principle

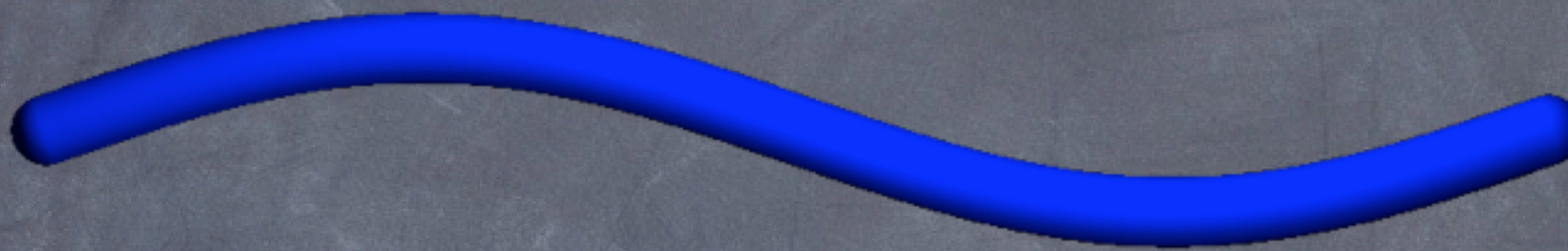


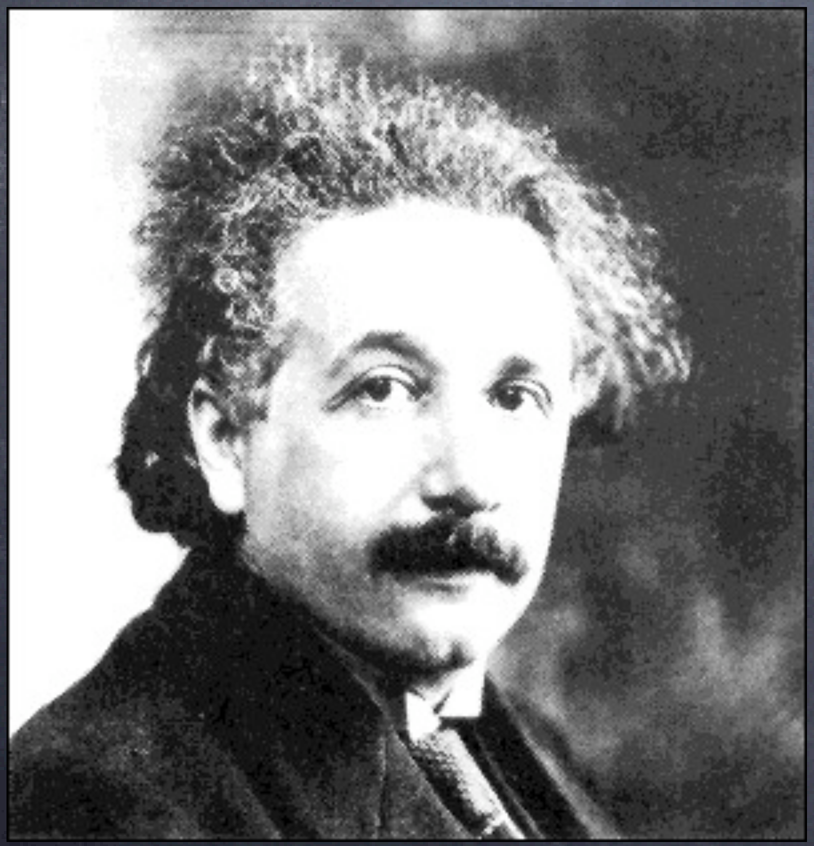
$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

$$\Delta E \, \Delta t \geq \frac{\hbar}{2}$$



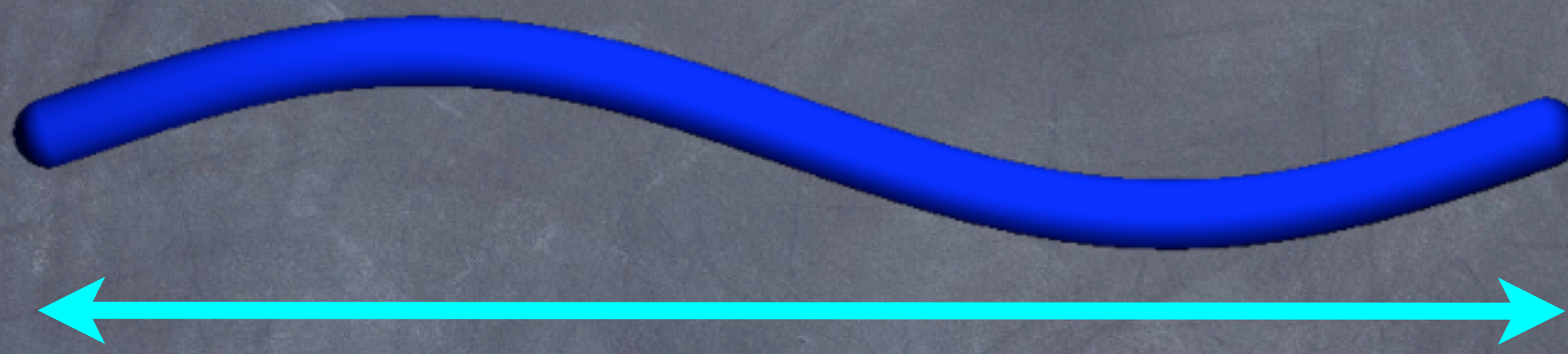
Light Waves





$$\text{Energy} \sim \text{frequency} \sim \frac{1}{\text{wavelength}}$$

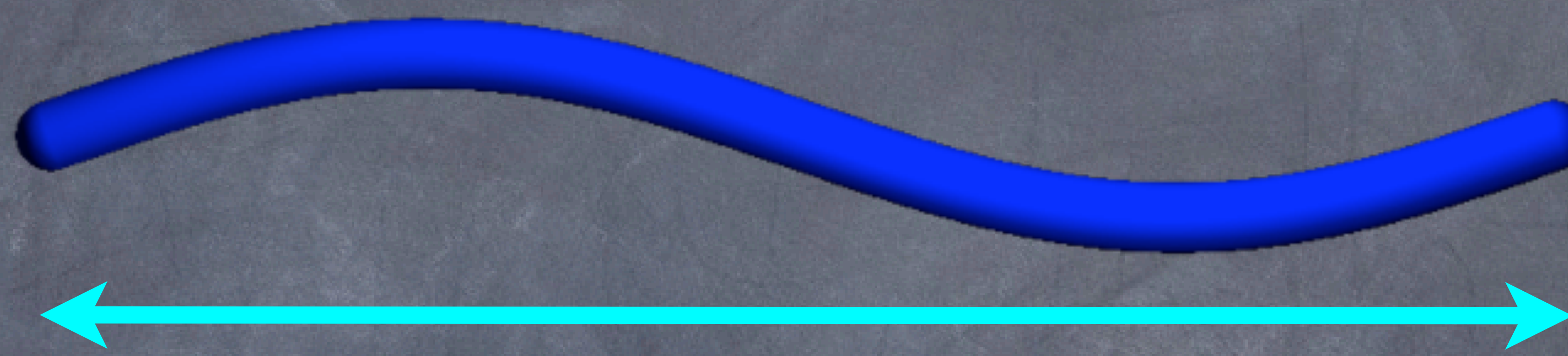
WiFi



wavelength = 5 in

Energy = $\frac{1}{100{,}000}$ eV

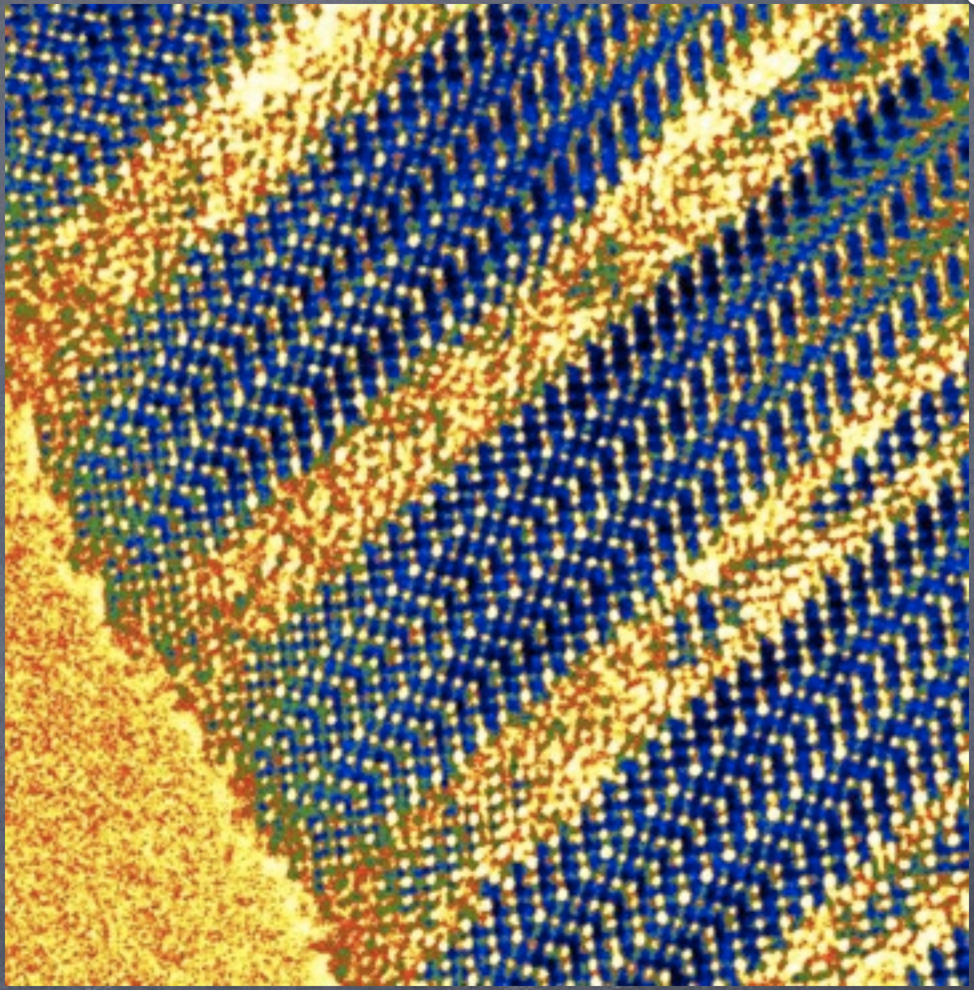
UV



$$\text{wavelength} = \frac{1 \text{ in}}{100{,}000}$$

Energy = 5 eV

Electron Microscope



wavelength = $\frac{1 \text{ in}}{100{,}000{,}000}$

Energy = 5000 eV

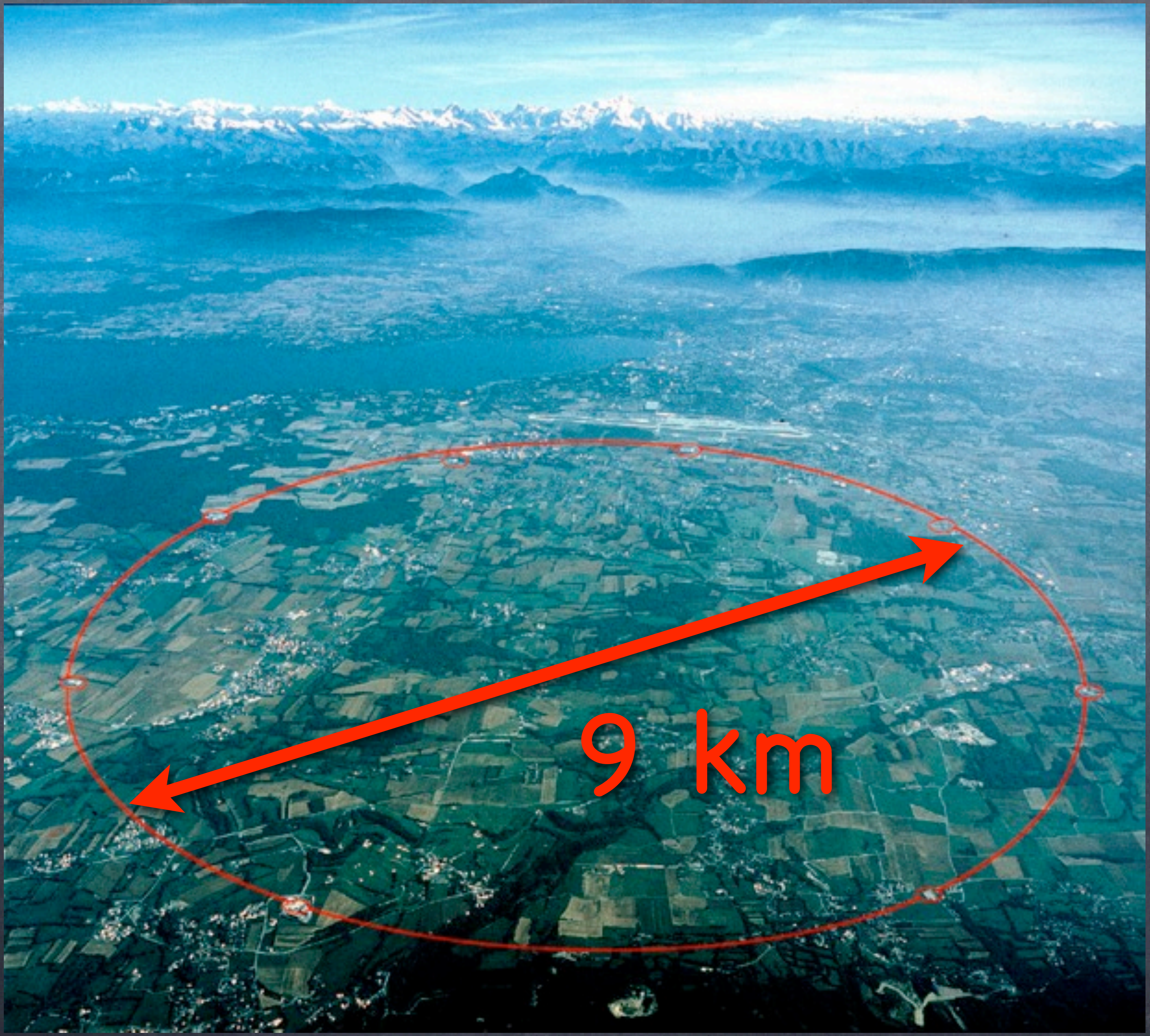
We Need

$$\text{wavelength} = \frac{5 \text{ in}}{1{,}000{,}000{,}000{,}000{,}000{,}000}$$

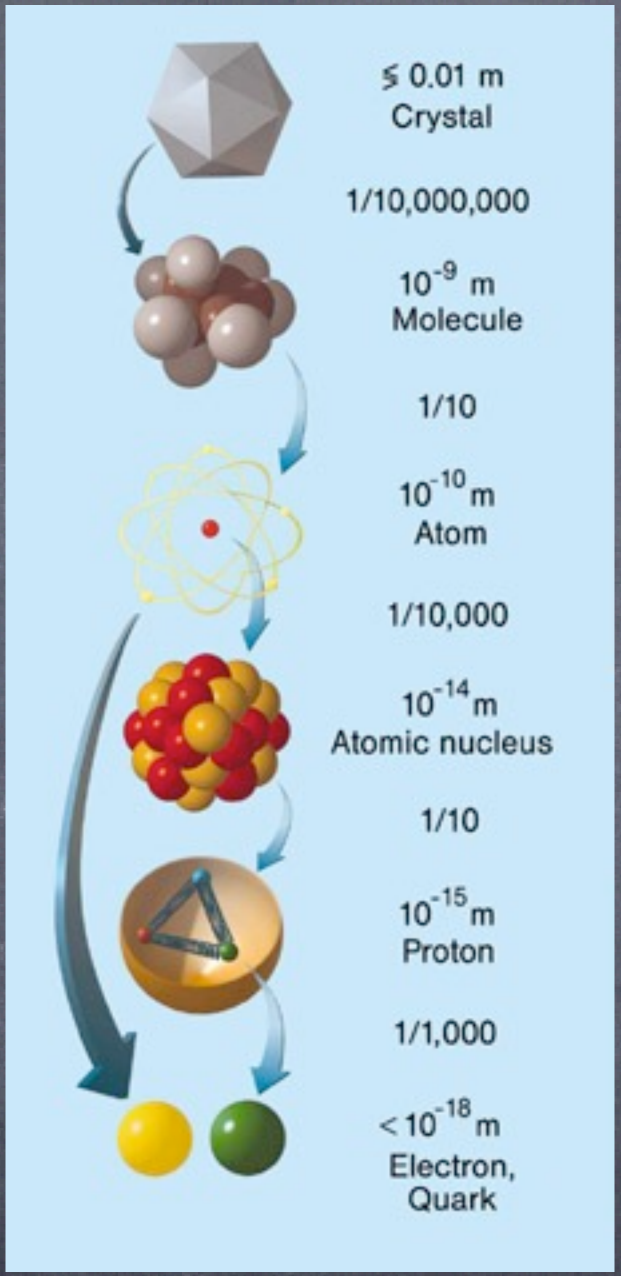
$$\text{Energy} = 10{,}000{,}000{,}000{,}000 \text{ eV}$$

Large Hadron Collider

Large Hadron Collider



Weak Scale vs Planck Scale



$\frac{1}{100000000}$ A

250 GeV

$\frac{1}{1000000000000000000000000000}$ A

10000000000000000000 GeV

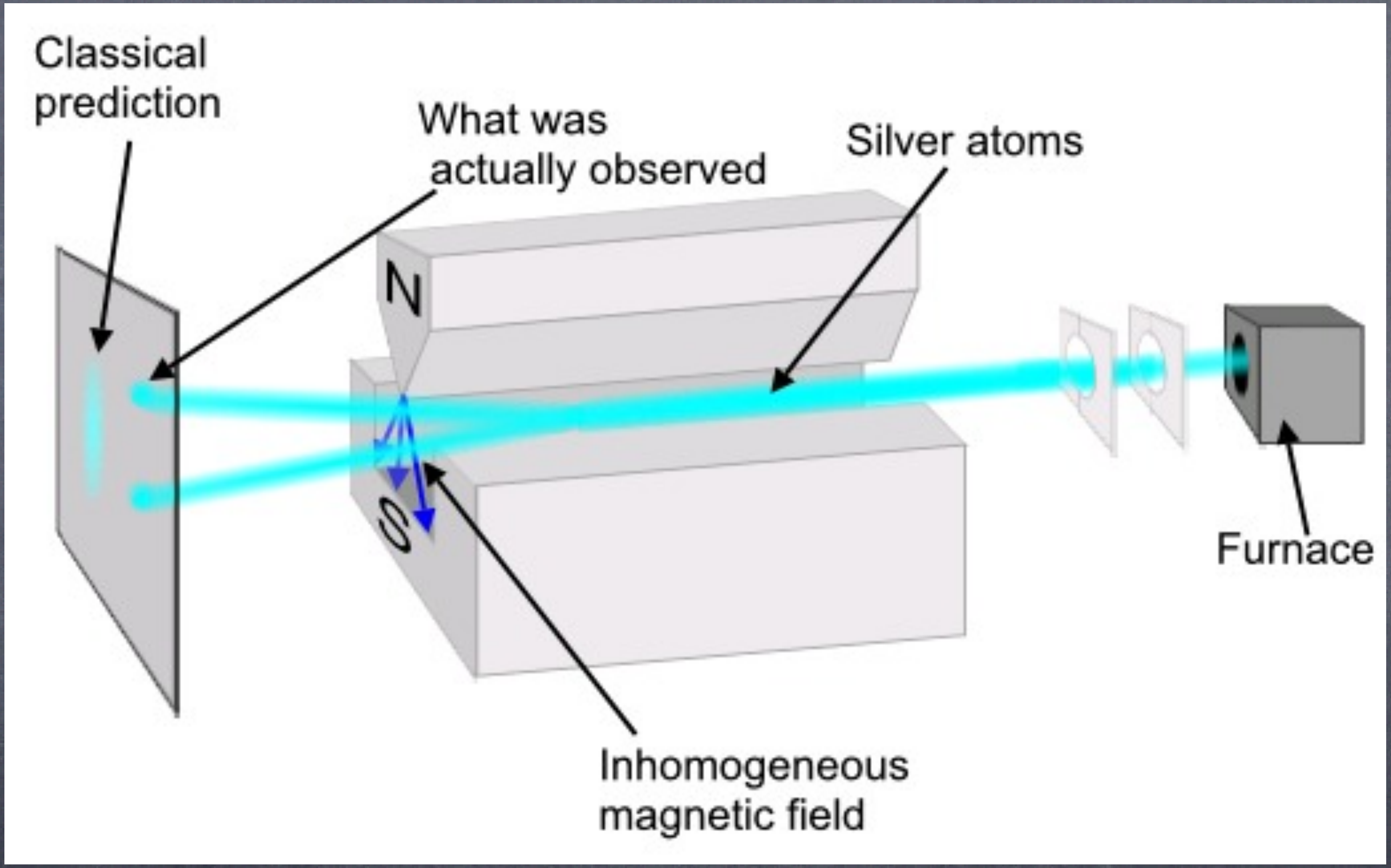
Quantum Spin

spin 0 1 2

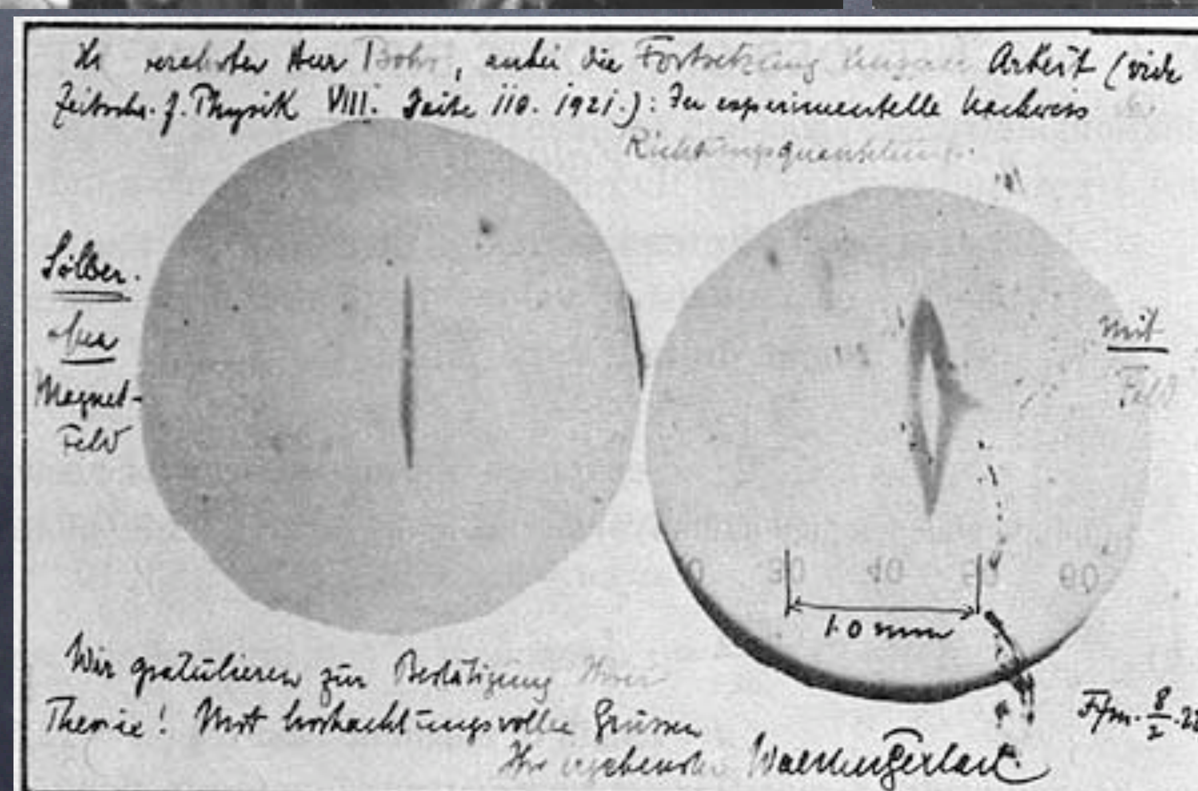
unchanged if we rotate by:

anything 360^0 180^0

Stern-Gerlach



Stern-Gerlach



Hochverehrter Herr Bohr, anbei die Fortsetzung unserer Arbeit (vergl. Zeitschr. f. Physik VIII. Seite 110. 1921): den experimentellen Nachweis der Richtungsquantelung.

Silber. Ohne Magnet-Feld

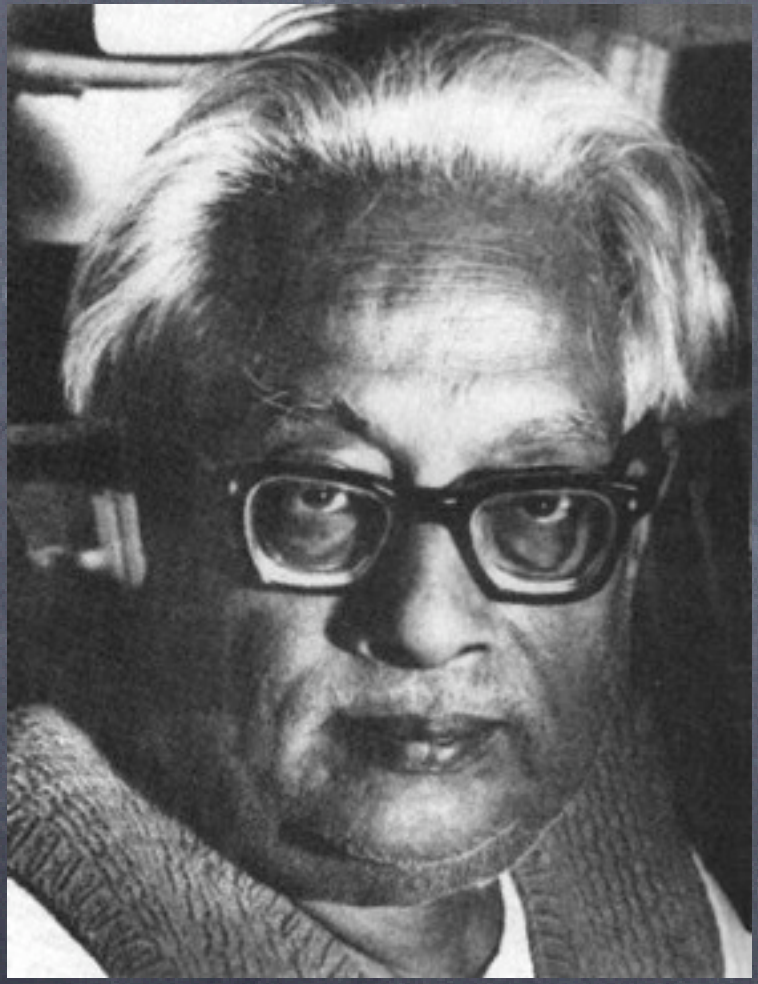
Mit Feld

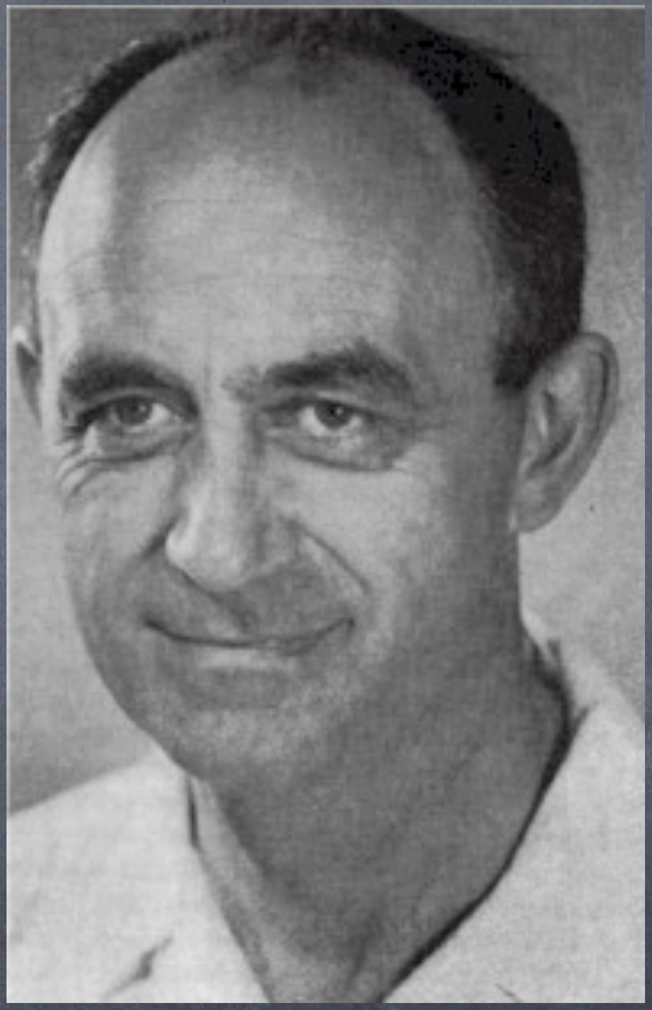
1.0 mm

Wir gratulieren zur Bestätigung Ihrer Theorie! Mit hochachtungsvollem Grüßen Ihr ergebenster Walther Gerlach

Ffm. 8/2. 22

Bose and Fermi





Fermion Spin

Fermion Spin

Rotate once

−1

Fermion Spin

Rotate twice

Fermion Spin

Rotate twice

$-1 \times -1 = +1$

Bosons and Fermions

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

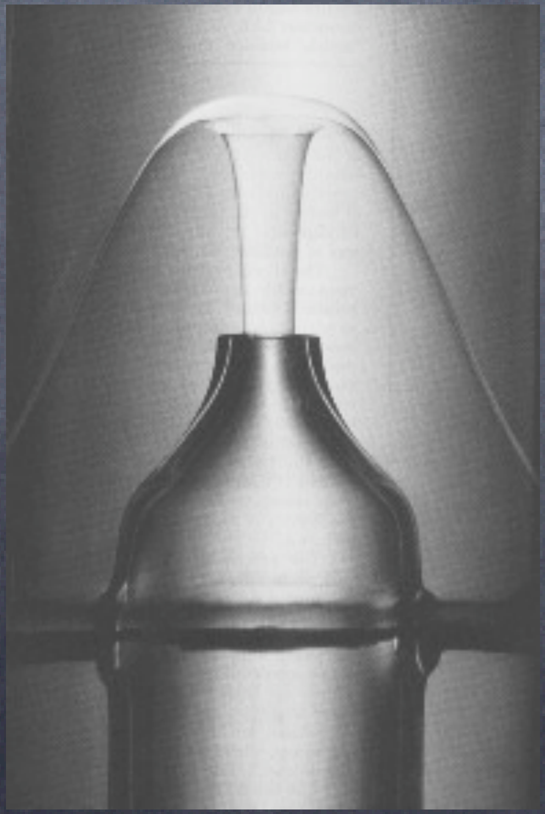
FERMIONS

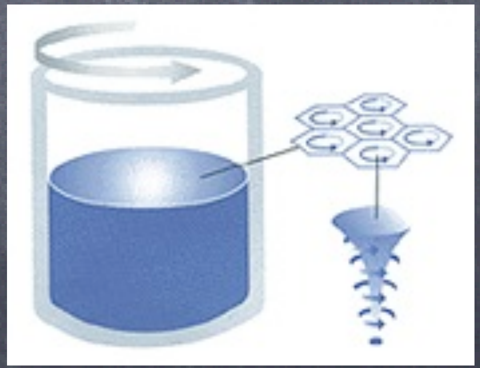
matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

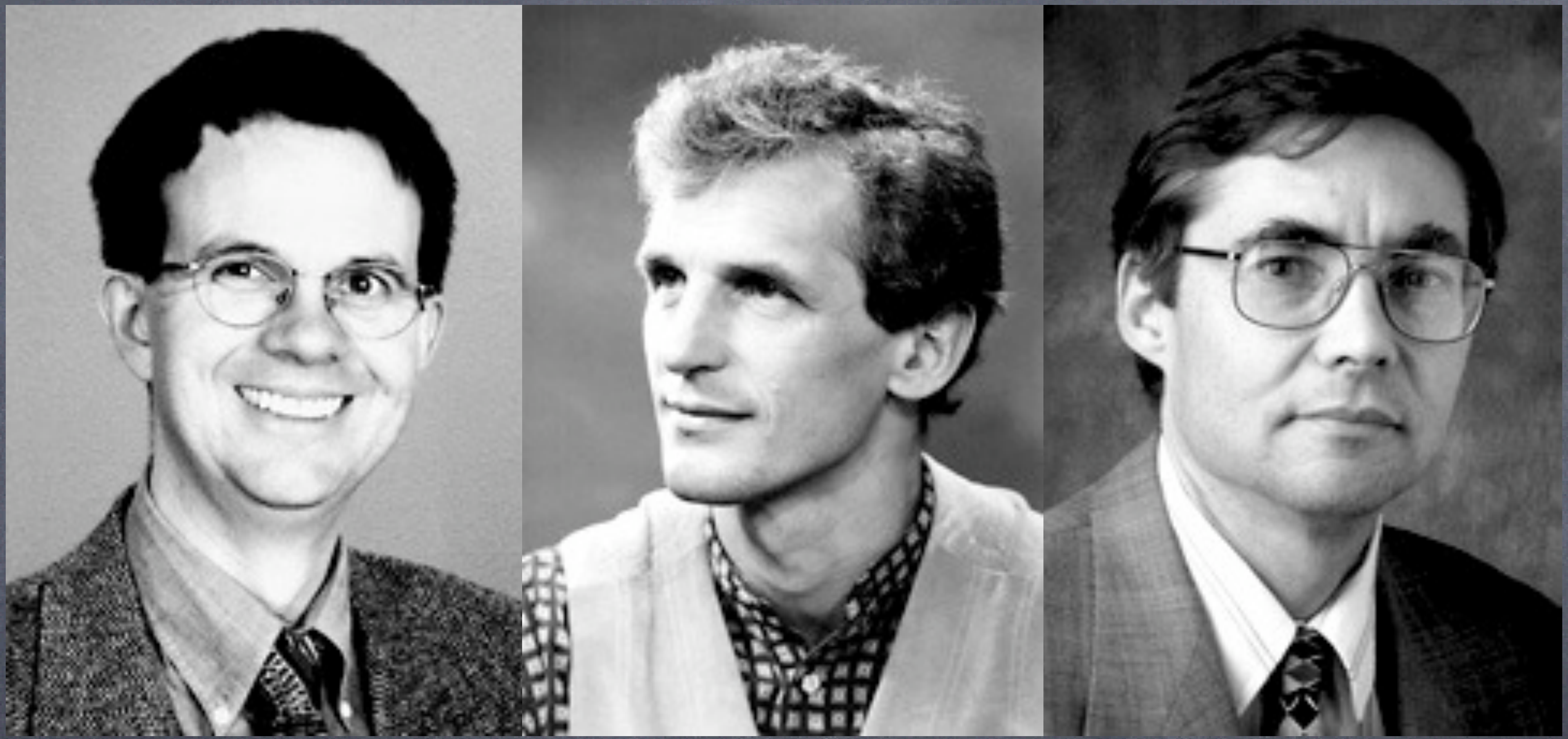
Superfluids: Bose-Einstein Condensation



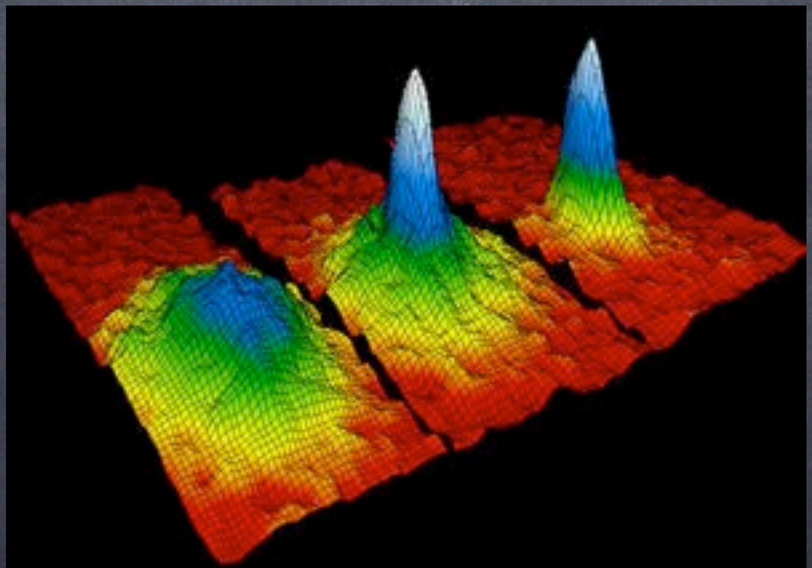


Superconductor

2001 Cornell, Ketterle, Wieman



velocity distribution



dilute gas of rubidium atoms

Pauli Exclusion