ASTRONOMY 103: THE EVOLVING UNIVERSE

Lecture 3

LIGHT: PARTICLES, WAVES, BLACKBODIES, AND LINES

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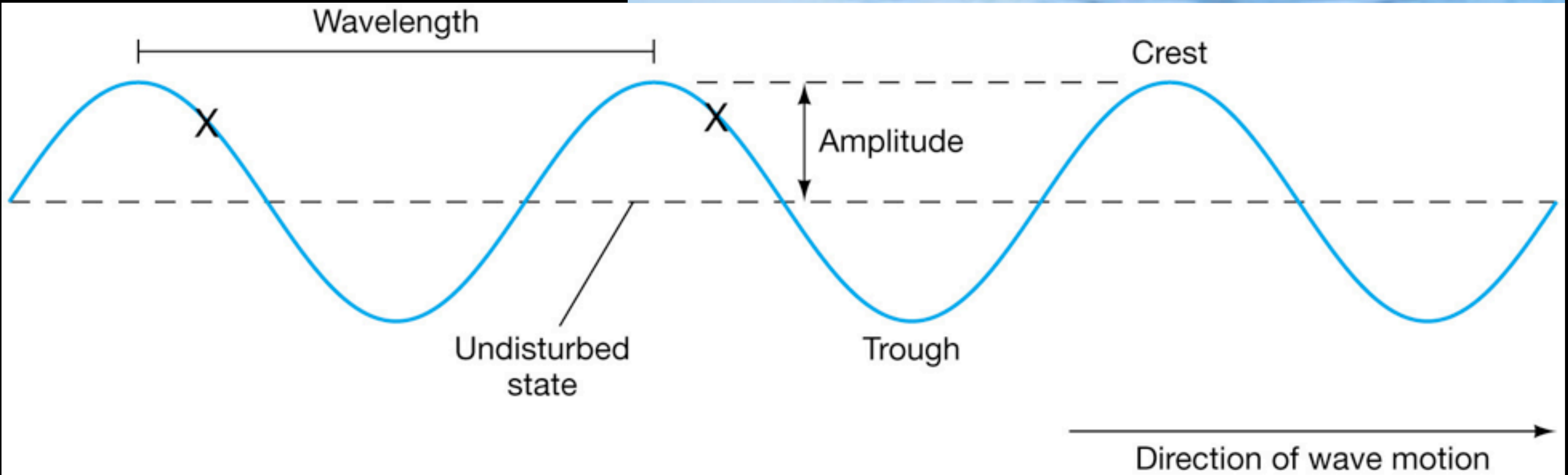
A Short Description of Waves

(rope demo)



Multiple Choice Question

Light is made up of photons, which are...

a) ...waves.
b) ...particles.
c) ...both waves and particles.
d) ...solid, flat beams or rays.
e) ...all part of one big wave that is everywhere all at once.

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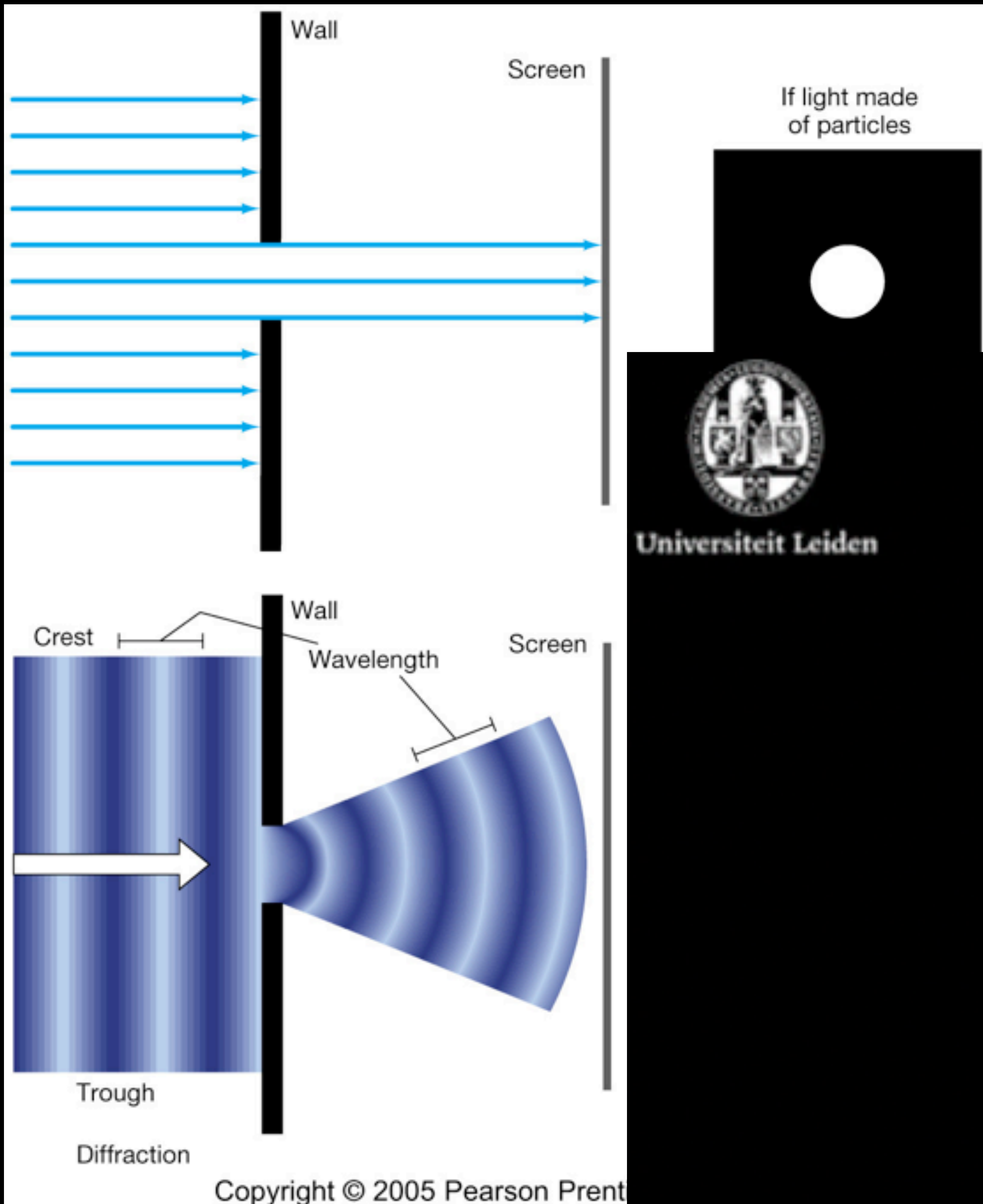


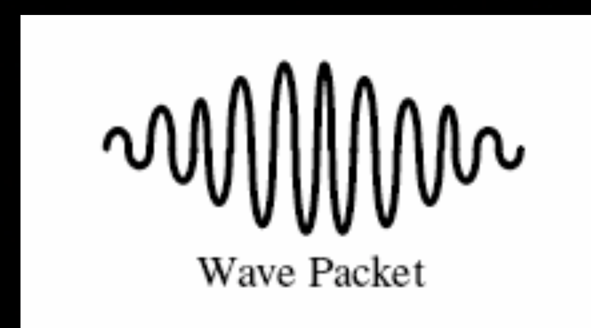
← Light comes in waves

Wave-Particle Duality

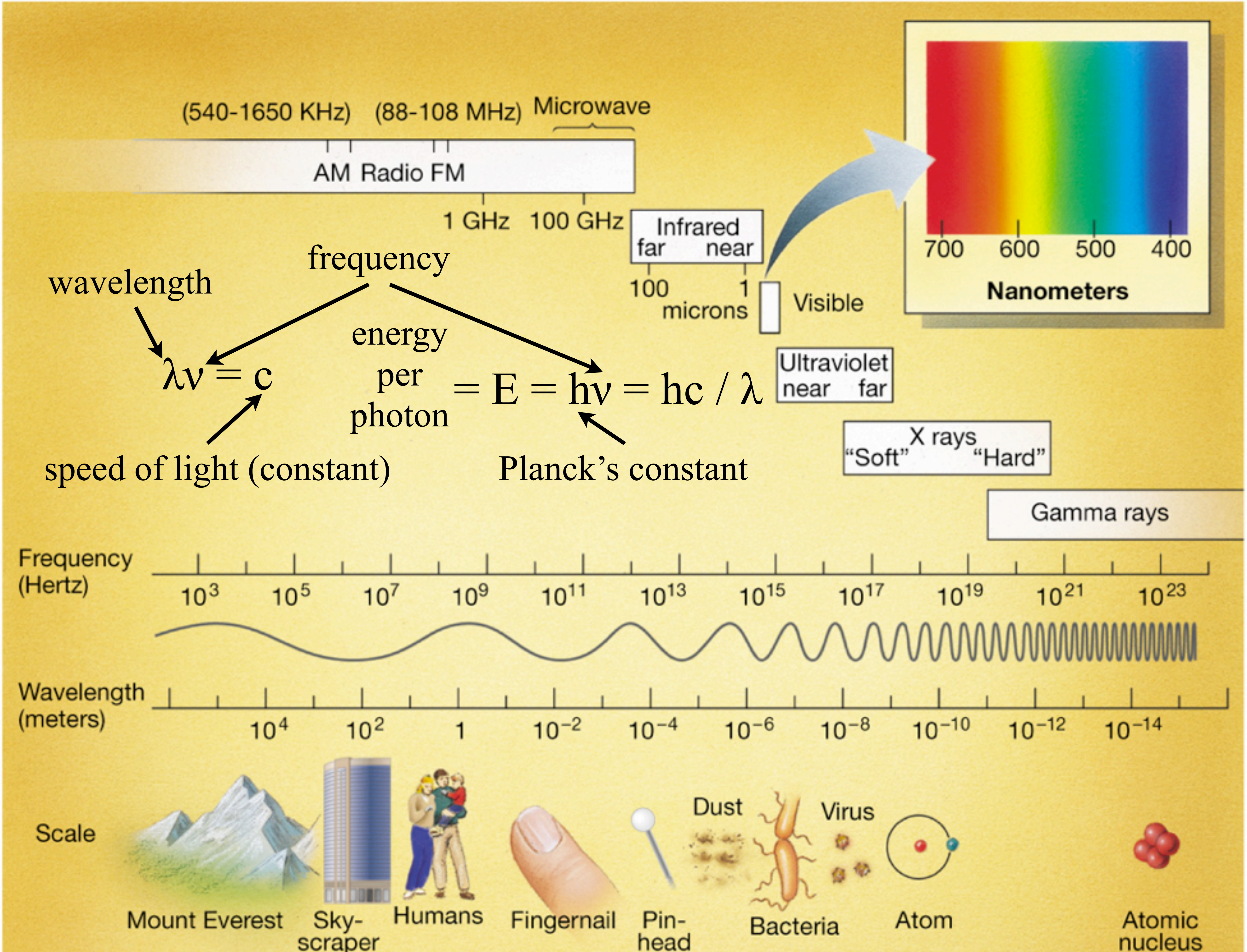
Light comes as particles ↓

Universiteit Leiden

0,025 msec



A Good Compromise: Light comes in discrete electromagnetic wave packets, called photons


(540-1650 KHz)
(88-108 MHz)
Microwave
AM Radio FM
1 GHz
100 GHz
Infrared
far near
100
1
microns
Visible
700
600
500
400
Nanometers
wavelength
frequency
energy per photon
$\lambda\nu = c$
$= E = h\nu = hc / \lambda$
speed of light (constant)
Planck's constant
Ultraviolet
near far
X rays
"Soft" "Hard"
Gamma rays
Frequency (Hertz)
10^3 10^5 10^7 10^9 10^{11} 10^{13} 10^{15} 10^{17} 10^{19} 10^{21} 10^{23}
Wavelength (meters)
10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14}
Scale
Mount Everest
Sky-scraper
Humans
Fingernail
Pin-head
Dust
Bacteria
Virus
Atom
Atomic nucleus

Two Types of Spectra

1. Discrete (ball demo)

light as seen through a grating or prism

Brightness = Number of Photons

λ (wavelength)

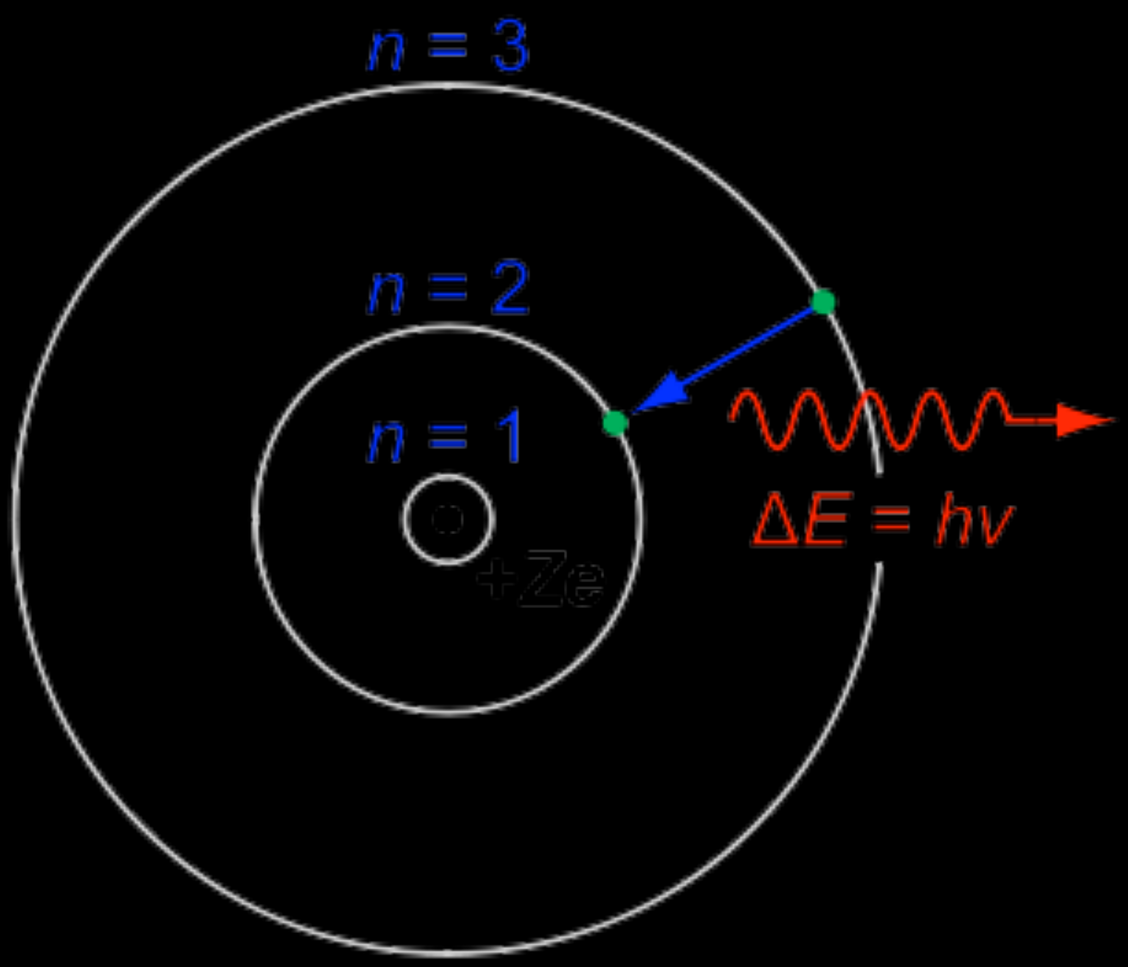
Why are some lines fainter than others?

- the probability that the atom will emit a photon changes from line to line (requires quantum mechanics)
- something (e.g., dust, gas) gets in the way to block (called “extinction”) or redirect (called “scattering”) the light; these two processes together “attenuate” the light

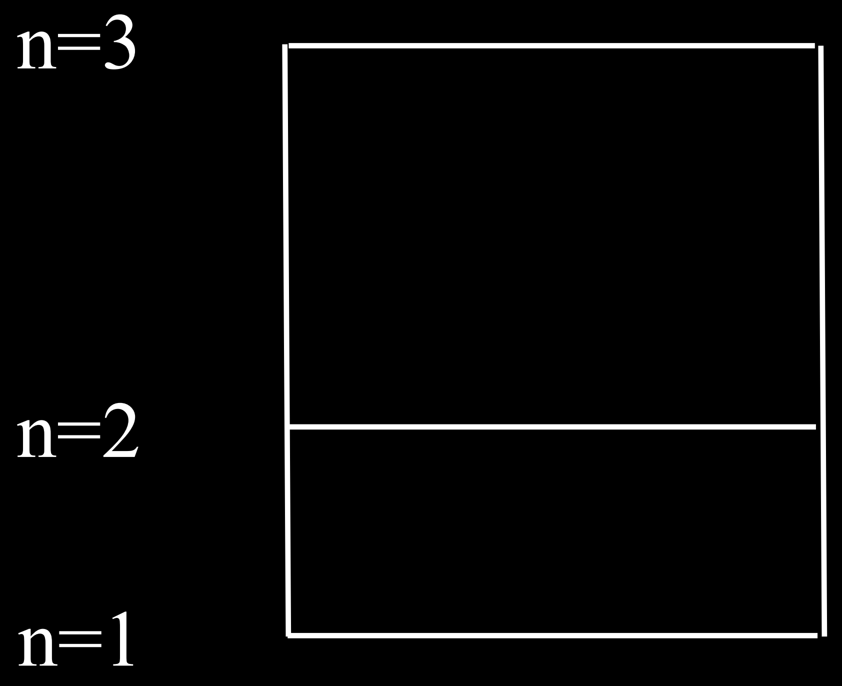
Two Types of Spectra

1. Discrete (ball demo)

Why do atoms only emit at discrete wavelengths?



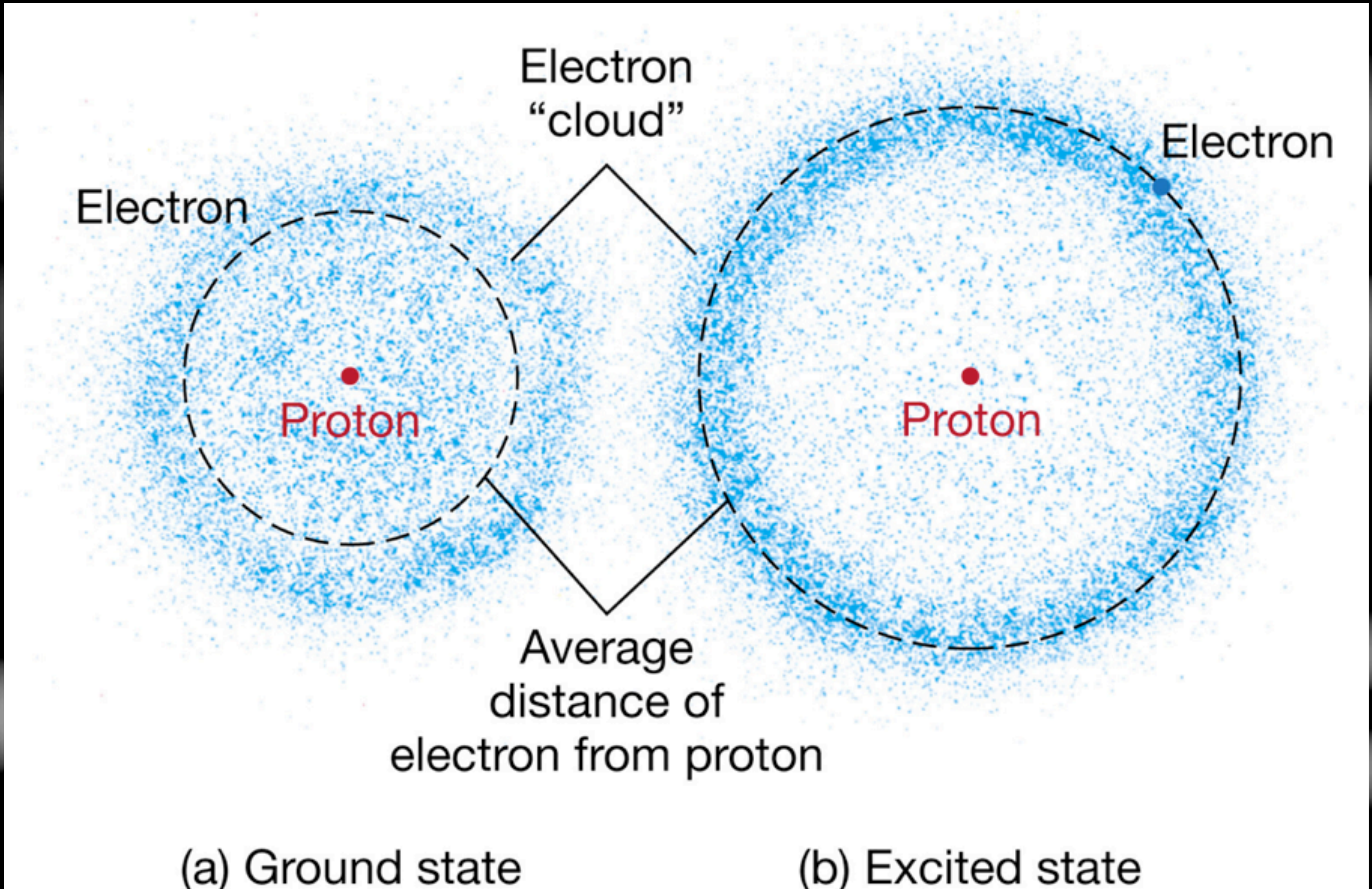
ladder schematic



The Uncertainty Principle

A basic result of quantum mechanics

$$\sigma_x \sigma_p \geq \frac{h}{4\pi}$$



Multiple Choice Question

Hα and Hβ are two lines emitted by the Hydrogen atom. Hα emits at a wavelength of 656.3 nm and Hβ emits at a wavelength of 486.1 nm. Which of the following statements are true?

a) Hβ emits at a lower frequency and lower energy than Hα.

b) Hβ emits at a lower frequency and higher energy than Hα.

c) Hβ emits at a higher frequency and lower energy than Hα.

d) Hβ emits at a higher frequency and higher energy than Hα.

e) There is not enough information to answer the question.

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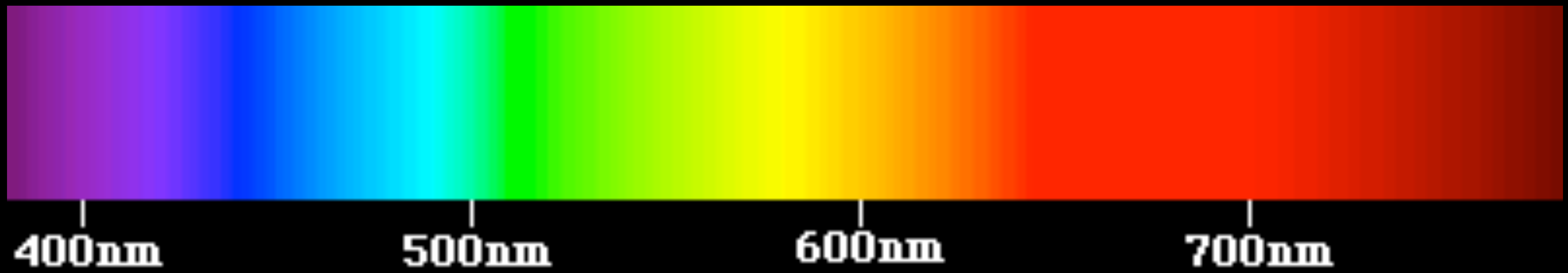
$\lambda\nu = c$ $\qquad$ $E = h\nu = hc / \lambda$

Two Types of Spectra

2. Continuous

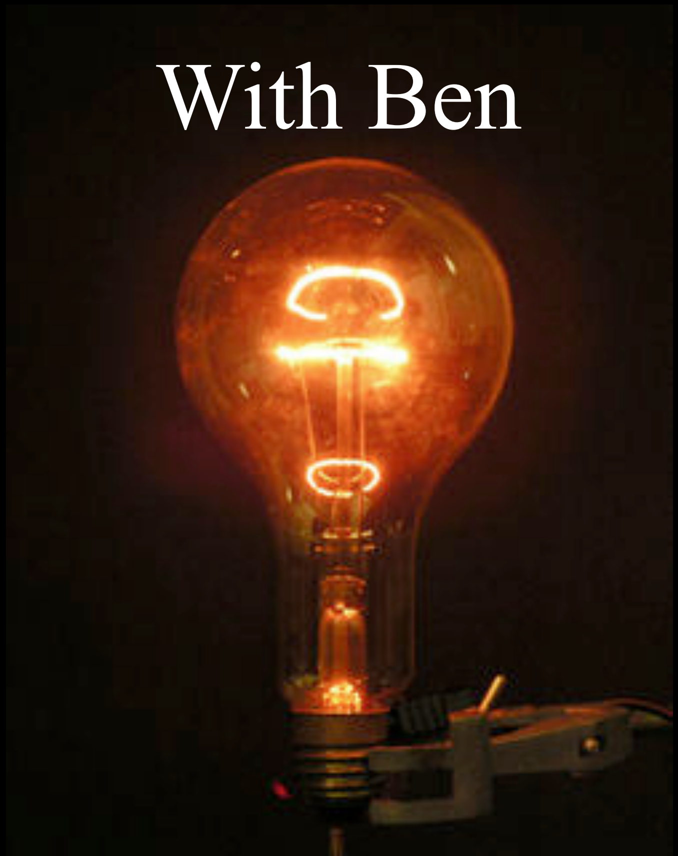


One very important type of continuous spectrum that you will see repeatedly throughout the semester: "Blackbody"

What is a blackbody?

- An ideal thermal emitter (object glows).
- A perfect absorber: no light is reflected so it appears black.
- Light comes from the heat of an opaque object.

Blackbody Examples:



Not Blackbodies:

A Blackbody Has a Characteristic Shape

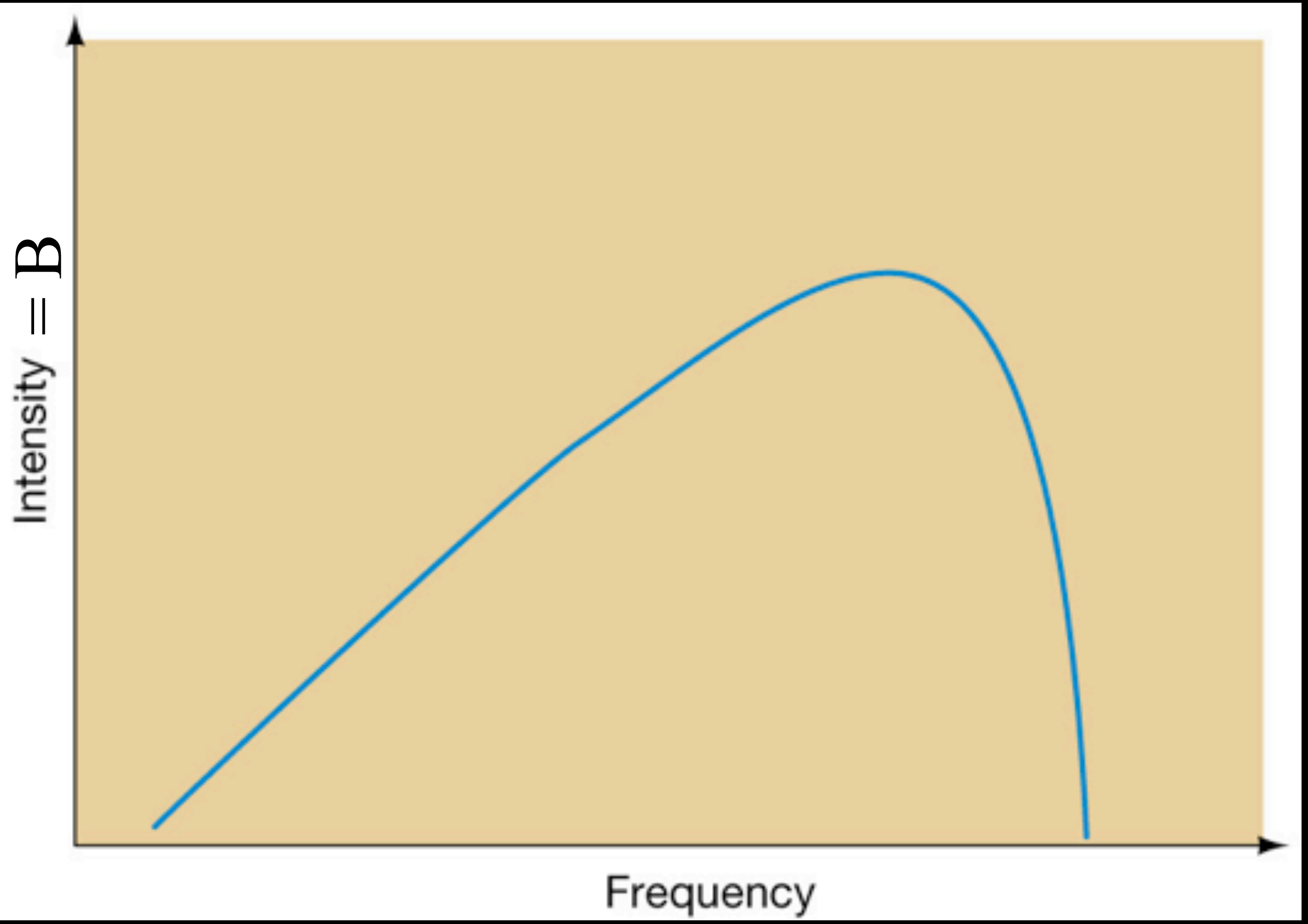
Blackbody Function = Planck Function

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{k_B T}} - 1}; \text{ or } B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}.$$

Rayleigh-Jeans Tail:

$$B_\nu(T) = \frac{2\nu^2 kT}{c^2}.$$

$$B_\lambda(T) = \frac{2ckT}{\lambda^4},$$



Wien Tail:

$$I(\nu, T) = \frac{2h\nu^3}{c^2}e^{-\frac{h\nu}{kT}} \qquad I(\lambda, T) = \frac{2hc^2}{\lambda^5}e^{-\frac{hc}{\lambda kT}}$$

Two Blackbody Trends

1. Wein's (Veen's) Law

$\lambda_p \propto 1 / T$

or

$\lambda_p = 2900 / T$

(λ_p is the "peak wavelength" in micrometers or microns and T is the temperature in Kelvin)

2. Stephan-Boltzman Law

$F_{tot} \propto T^4$ or $F_{tot} = \sigma T^4$

(F_{tot} is the "total flux" or the amount of photons emitted per unit area from the surface of the object)