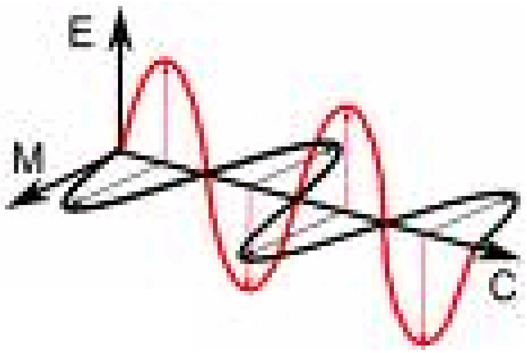
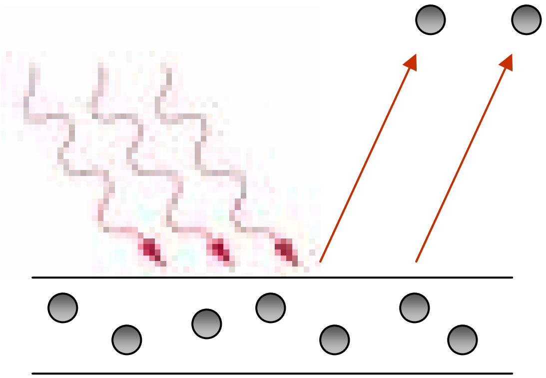
Development of QM

What do we know from classical physics?



1. Energy can take any continuous value.

2. Electromagnetic radiation is an electric field oscillating perpendicular to the direction of propagation.



3. Any frequency of light with enough intensity should cause an e^- to be emitted from a metal.

4. Light is a wave.

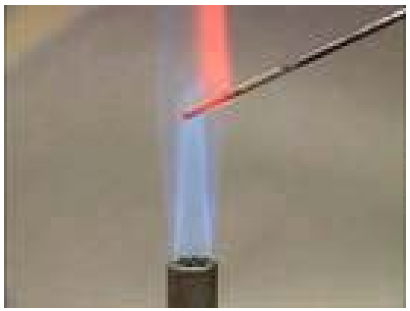
Contradictions to Classical Physics

1. Blackbody Radiation
2. Photoelectric Effect
3. Emission Spectra of Atoms
4. Rutherford's Backscattering Experiment

Blackbody Radiation

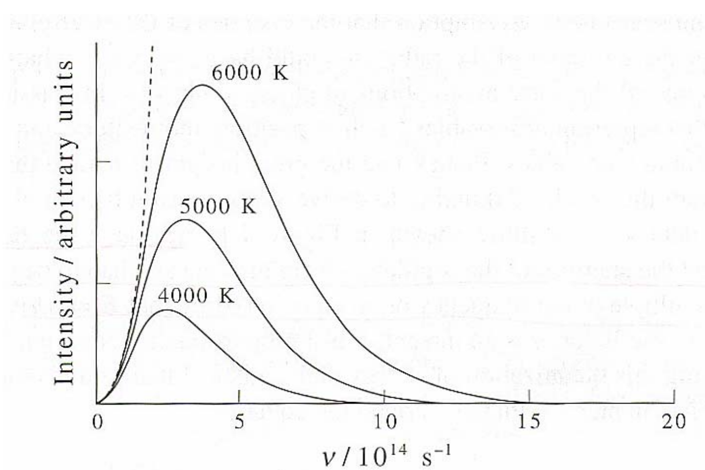
1-3

Picture a metal bar heating in a fire…



Observe: Radiation emitted in higher and higher frequency (red→blue) as temperature increases

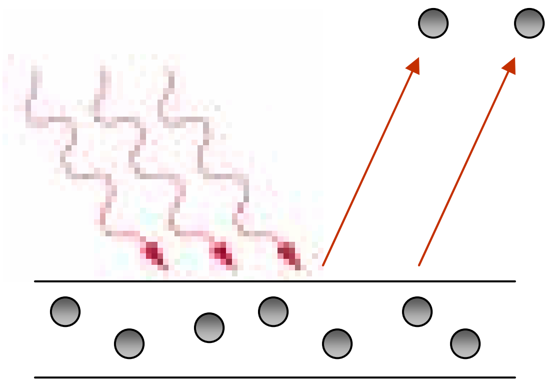
The shift in frequency can be measured, but couldn't be explained by classical physics.



Caution: Sitting near recreational fires, such as bonfires, can lead to death from radiation exposure within hours.

Photoelectric Effect

Photoelectric effect = UV light impinging on a metallic surface causes electrons to be ejected.



Classical physics couldn't explain two experimental observations:

1. K.E. of ejected e^- is independent of the intensity of incident radiation.
2. There is a threshold frequency, ν_0, that is characteristic of each metal.

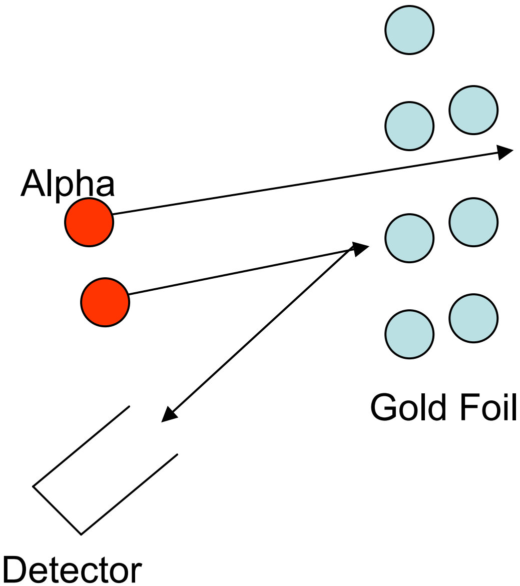
Rutherford's Experiment

Rutherford's experiment: α particles shot at thin gold foil … some particles passed through foil but some were scattered.

Rutherford's hypothesis: atoms in the gold consisted of a heavy, positively charged nucleus with negatively charged electrons orbiting nucleus.

Classical physics: A moving charge emits radiation, causing the charge to slow down. As it slows, the centrifugal force decreases and electron falls into the nucleus.

Ernest Rutherford



Rutherford's Experiment

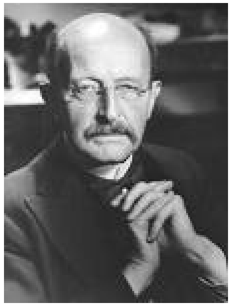
Rise of Quantum Mechanics

A new theory was needed, and was ultimately developed, to explain these observations and experiments… <u>Quantum Mechanics</u>!

Quantum Mechanics …

1. is <u>not</u> a correction to classical mechanics.
2. is a foundation for understanding *all* chemistry.
3. is a new way of describing the mechanical properties of very **light** objects.
4. sometimes contradicts what we observe macroscopically.
5. does explain observations on the microscopic scale.

Blackbody Radiation - Redux



Max Planck

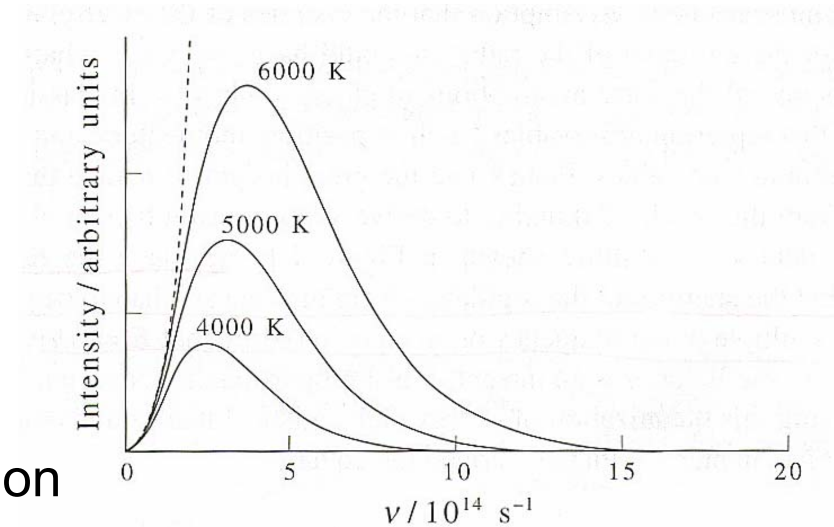
Max Planck assumed the oscillating electric field of EM radiation had discrete energies and were proportional to the frequency. ..

$$E = nh\nu$$

where n = an integer, h = Planck's constant, ν = frequency

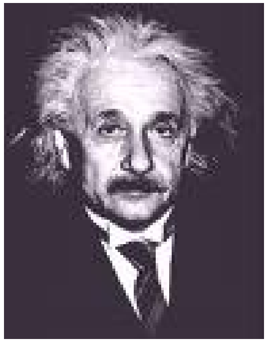
With this assumption, blackbody radiation observations can be explained by:

$$d\rho(\upsilon,T) = \rho_\upsilon(T)d\upsilon = \frac{8\pi h}{c^3}\frac{\upsilon^3 d\upsilon}{e^{h\upsilon/k_BT}-1}$$



To match experimental blackbody radiation measurements, h=6.626×10^{-34} J·s.

Einstein & The Photoelectric Effect


Einstein

Einstein expanded Planck's theories, proposing that radiation (e.g., light) exists as small packets of energy… photons.

$$KE_{e-} = h\nu - \varphi$$

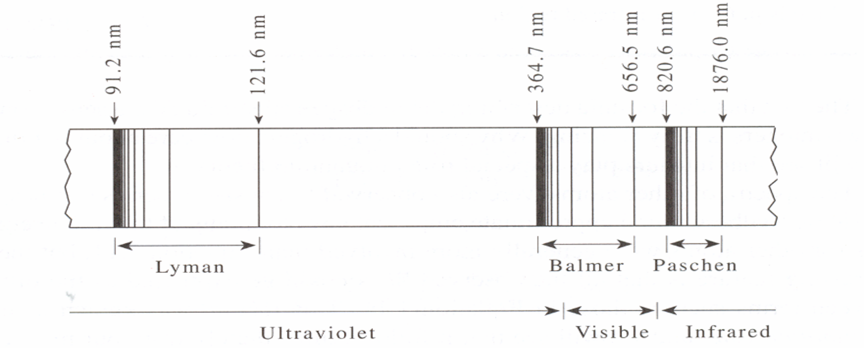
Energy of light ($h\nu$) — Work function (φ)

Work function: minimum energy needed to remove electrons from a specific metal.

Einstein's theory explains all observations about the photoelectric effect.

Hydrogen Atomic Spectrum

$$\tilde{\upsilon} = \frac{1}{\lambda} = \frac{\upsilon}{c}$$



Johann Balmer

Balmer determined that the visible emission spectrum of the H atom can be described by:

n = 3, 4, …

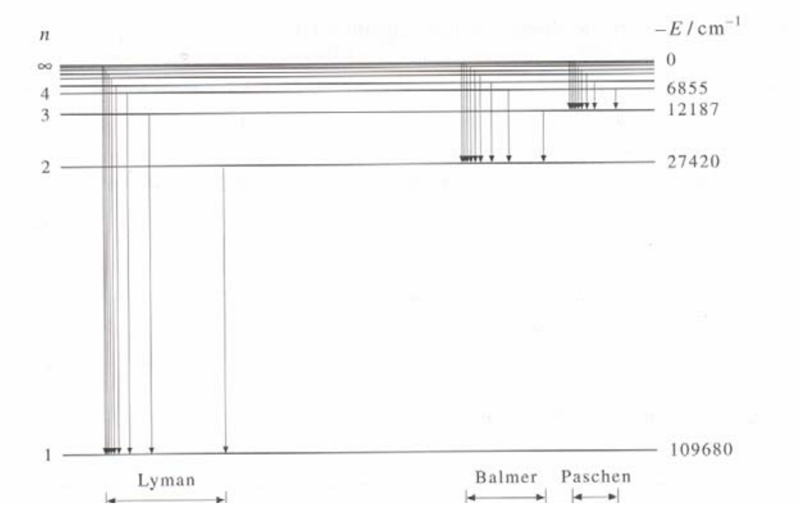
$$\upsilon = 8.2202 \times 10^{14}\left(1 - \frac{4}{n^2}\right) \quad \text{or} \quad \tilde{\upsilon} = 109680\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Johannes Rydberg

Rydberg generalized this formula to account for all of lines in the H atomic spectrum:

$$\tilde{\upsilon} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$n_2 > n_1$, R_H = 109677.57 cm^{-1}



Niels Bohr and the Atom

Niels Bohr

To explain Rutherford's backscattering experiments, Bohr assumed:

1. Electrons have stationary orbits.
2. The de Broglie waves of the orbiting electron must be in phase.

With these assumptions, the angular momentum of an electron, the radii of electron orbits, and the energy levels can be determined. **<u>All</u>** are **<u>QUANTIZED</u>**!!

Angular Momentum: $$m_e \upsilon r = \frac{nh}{2\pi} = n\hbar$$

n = 1, 2, 3…

Radii of orbits: $$r = \frac{\varepsilon_0 h^2 n^2}{\pi m_e e^2} = \frac{4\pi\varepsilon_0 \hbar^2 n^2}{m_e e^2}$$

At n = 1 … Bohr radius … $r = 5.292 \times 10^{-11}$ m = 52.92 pm = a_0

Energy: $$E = KE + V(r) = \tfrac{1}{2} m_e \upsilon^2 - \frac{e^2}{4\pi\varepsilon_0 r} = -\frac{e^2}{8\pi\varepsilon_0 r}$$ $$E_n = -\frac{m_e e^4}{8\varepsilon_0 h^2 n^2}$$

n = 1 is ground-state energy, n = 2,3,4… are excited states

Summary of Chapter 1

- Classical physics was unable to explain some observations on the microscopic scale.
- Heisenberg, Schrödinger, Dirac, and others formulated a new mechanics – Quantum Mechanics.
- These slides summarize some of the important concepts leading to the development of QM – read your book (and others) for more details!