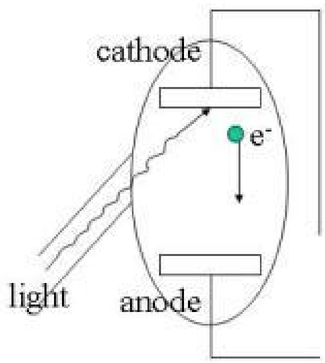


1. Photoelectric effect (Hertz 1887)

Photoelectric effect
(Hertz 1887)



- Light on metal "boils off" electrons - makes a current (amps)
- Fix Voltage V (or electric force) across tube
- Measure current vs. f and light intensity I
- Vary V

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2. Photoelectric effect and photons

Photoelectric effect and photons

- Einstein explains effect: Planck's quantum becomes E=hf packet of EM energy or photon (γ)
  - For $\lambda \approx 5\text{x}10^{-7}$ m have $f = c/\lambda =$
    $3\text{x}10^{8}$m/s / $5\text{x}10^{-7}$ m $= 6\text{x}10^{14}$ sec^{-1}
  - Then E(photon) = h f = $6.6\text{x}10^{-34}$ J·s · $6\text{x}10^{14}$ s^{-1}
    $= 4\text{x}10^{-19}$ J = 2.5 eV
- Why don't we see these photons? Consider an everyday source of light:
- How many γ's from 40 Watt light bulb? 1W=1J/sec
  Take average $\lambda \approx 5\text{x}10^{-7}$ m, so each γ carries $4\text{x}10^{-19}$ J.
  Then number of γ's per second is 40 J/s / $4\text{x}10^{-19}$ J = 10^{20}/sec
- (What about light from warm objects in ordinary environment?
  measure of thermal energy is kT
  where k=Boltzmann's constant, T=temp in Kelvin (=Centigrade+273)
  So at T=290 K (room temp) thermal energy is
  $1.38\text{x}10^{-23} \cdot 290 \approx 4.0\text{x}10^{-21}$J $\approx 2.5\text{x}10^{-2}$ eV corresponds to $\lambda \approx 5\text{x}10^{-5}$ m)

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3. Quantum theory of photoelectric effect

Quantum theory of photoelectric effect

- Einstein(1905): Light = photons = quanta
- and $E = hf$ Wave-particle duality
- Photon hits electron in metal giving e^- energy to escape (e^- loses some in getting out)
- Max Kinetic Energy of electron = KE_{max} $= 1/2\, mv_{max}^2 = eV_S$ (stopping voltage) = hf
- KE_{max} is independent of Intensity (power/area)
- electrons can not absorb all I, only 1 e^- per 1 γ
- Will need to think of probability for γ s to be emitted or absorbed - will review soon

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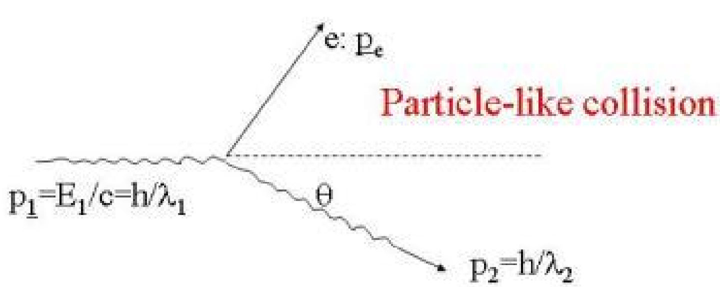
4. Compton Scattering (A.H. Compton 1923)

Compton Scattering (A.H. Compton 1923)

$\gamma_{X\text{-}Ray} + e_{atomic} \rightarrow \gamma + e$ (for $E\gamma >> K_e, U_e$ so e ~ free and at rest)

Result $\lambda_{in} \leq \lambda_{out}$



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5. Atomic Spectra

Atomic Spectra

- Consider the elements in the periodic table
- Chemistry involves interactions among these elements
- Each element is an atom - electrons (negative charges) & positive nucleus - usually neutral - atomic properties depend on the electrons mostly
- We have considered nuclei in regard to releasing rest energy, but now step back to atoms (~ 5 orders of magnitude bigger!)
- Each element has characteristic discrete EM spectral lines (1880's)

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6. Atomic Spectra

Atomic Spectra

- Each element has characteristic discrete EM spectral lines (1880's)
- H (& single e atoms) Rydberg-Ritz formula
  $f = cRZ^2(1/n_2^2 - 1/n_1^2)$ for $n_1 > n_2$
  $R_\infty = 10.97373\ (\mu m)^{-1}$ Rydberg constant(for heavy elements)
  Z = atomic number
- Why discrete spectrum?
- Rutherford atom ruled out Thompson's "plum pudding" model and supported "solar system" model
  Atom r ~ $10^{-9 \text{ or } -10}$m but nucleus r ~1 fm or 10^{-15} m
- Why don't orbiting electrons radiate?

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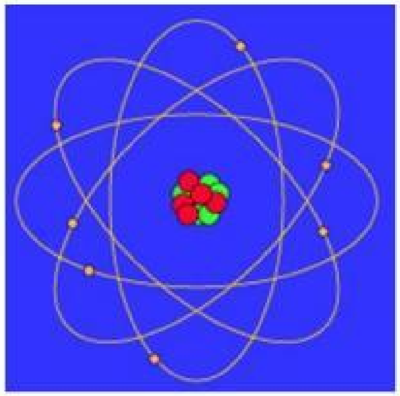
7. Models of the atom

Models of the atom



Planetary model - electrons around nucleus
Why don't electrons radiate as Maxwell predicts?

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8. Planetary model

Planetary model

- (Classical) electrons are bound to positive nucleus by electric attraction (Coulomb's Law: $F(r) \propto 1/r^2$) into stable orbits
  - $v^2 \propto 1/r$ and $E \propto 1/r$ for circular orbit at **any *r***
- Like gravitational orbits of planets but much smaller scale - combination of "coupling strength" and properties of matter (clue to unification?)
  - gravitational force $\propto G \bullet mass_1 \bullet mass_2$
  - Coulomb force $\propto e^2 \bullet$ no.charges(1) $\bullet$ no.charges(2)

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9. Bohr’s model

Bohr’s model

- Bohr: Only discrete orbits allowed - quantum condition for angular momentum - Quantization
  $mvr = nh/2\pi$ (n integer) => $r_n \propto n^2$ and $E_n \propto 1/n^2$

=> Only discrete energies are allowed - Emission and absorption of photon when E changes from one discrete value to another

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10. Transition example

Transition example

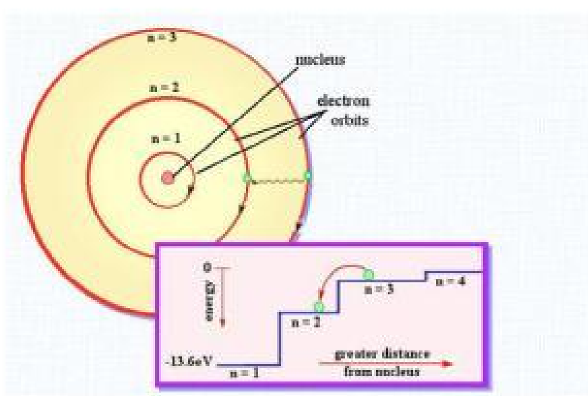

Image adapted by M. Nguyen

Orbits
energy

Quantized
energies

Quantum jumps
energy released

Photon energy hf

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11. H atom energies

H atom energies

- Bohr calculated discrete energies of orbiting electrons in H atom (note minus sign)

  E_1=-13.6 eV, E_2=-13.6/4 eV = $E_1/2^2$,

  E_3=-13.6/9 eV = $E_1/3^2$, ...

  $E_n=E_1/n^2$
- Allowed orbits labeled by n
- Higher Z atoms, more electrons
- Pauli exclusion principle explains others (later)

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12. Radiative transitions

Radiative transitions

electron jumps from orbit i to j which releases photon

$$hf = E_i - E_j = E_1 / n_i^2 - E_1 / n_j^2$$

Agrees with Rydberg formula!
Quantum jump occurs.
When? Random - exponentially decreasing probability distribution with an average lifetime.

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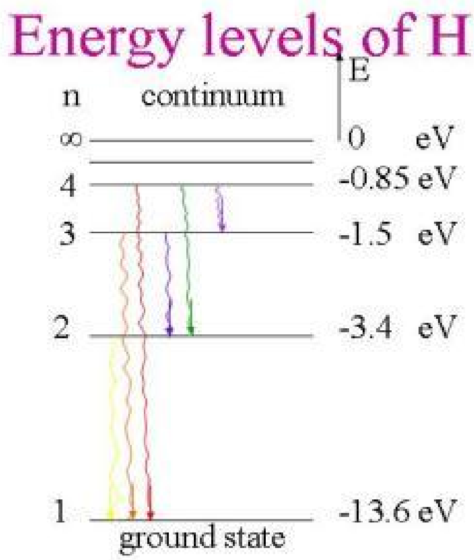
13. Energy levels of H



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14. Spectral lines of H

Spectral lines of H

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