1 The Photoelectric Effect

photoelectric effect: the emission of electrons from the surface of a conductor when light strikes the surface.
thermionic emission: the escape energy is supplied by heating the material to a high temperature.
work function: the minimum amount of energy an individual electron has to gain in order to escape from a particular surface.
cathode: negatively charged electrode.
anode: positively charged electrode.
threshold frequency: the minimum frequency, f, required for electron emission.

Stopping potential

> The reversed potential difference required to stop the electron flow completely is called the stopping potential, denoted by V_0.

quanta: small bundles of energy.

Energy of a photon

> The energy E of an individual photon is equal to a constant times the frequency f of the photon; that is,
>
> $$E = hf$$
>
> where h is a universal constant called **Planck's constant**. The numerical value of h, to the accuracy presently known is
> $$h = 6.62606957(29) \times 10^{-34} \text{J} \cdot \text{s}.$$
>
> This improved value was brought you via a very small part of your Tax dollars by the NIST. Fundamental constants are used to create better electronic and optical machines that are used in medical equipment (treatment, research), GPS and satellite systems (cellular phones, Search and Rescue), computers and millions of other devices that are used throughout the world to make life a little more enjoyable, safer, and longer.
>
> The more we know, the more we can do. Happy Tax Day.

Electronvolts in terms of Joules: $1\text{eV} = 1.602 \times 10^{-19}$ J.

Planck's constant in terms of electronvolts: $h = 4.136 \times 10^{-15}$ eV $\cdot$ s.

Photon frequency and wavelength

> The concept of photons is applicable to all regions of the electromagnetic spectrum, including radio waves, x rays, and gamma rays. Photons always travel with the speed of light, c. A photon of any frequency f and wavelength $\lambda = c/f$ has energy E by
> $$E = hf = \frac{hc}{\lambda}.$$

2 Line Spectra and Energy Levels

spectrum: (for our study) the separation of the various wavelengths of light.
line spectrum: a spectrum that has discrete bands for each wavelength.

If E_i is the initial energy of an atom before a transition from one energy level to another, E_f is the atom's (smaller) final energy after the transition, and the energy of the emitted photon is hf, then

$$hf = E_i - E_f.$$

Balmer's formula for the hydrogen spectrum

Balmer's formula is

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right),$$

where λ is the wavelength, R is a constant called the Rydberg constant, and n may have the integer values 3, 4, 5,.... If λ is in meters, the numerical value of R (determined from measurements of wavelengths) is

$$R = 1.097 \times 10^7 \mathrm{m}^{-1}.$$

ground state: the lowest energy level (or energy state) of an atom representing the minimum energy the atom can have.
excited state: all states with energy greater than that of the ground state.
lifetime: the average time spent in the excited state.
continuous emission spectrum: a spectrum with a continuous distribution of wavelengths, not a line spectrum.
blackbody: an ideal absorber of radiation that emits a continuous distribution of wavelengths.

3 The Nuclear Atom and the Bohr Model

Rutherford scattering: alpha particles projected onto atoms and the resulting deflection.
scintillation: momentary flash caused by a particle being absorbed and re-emitted by certain materials.
Geiger counter: a device commonly used to detect radiation.
nucleus: positively charged, dense core of the atom consisting of neutrons (neutral) and protons (positive).
Bohr model: a mechanical model of the hydrogen atom proposed by Bohr using the relationship between spectral wavelengths and energy levels.
stable orbits: path of the electron revolving around the nucleus that do not decay and do not emit radiation (contrary to classical electromagnetic theory).
quantized: in regards to the electron orbit, the angular momentum L has only specific (i.e. discrete) values with integer multiples of $h/2\pi$.

Quantization of angular momentum in the Bohr model

In Bohr's hypothesis, the allowed values of angular momentum L for an electron in a circular orbit are given by

$$L = m\nu r - n\frac{h}{2\pi}, \quad n = 1, 2, 3, ...$$

Radius and speed of Bohr orbits

In the Bohr model, an electron in a state with quantum number n has orbit radius r_n and speed ν_n given respectively by

$$r_n = \epsilon_0 \frac{n^2 h^2}{\pi m e^2},$$

$$\nu_n = \frac{1}{\epsilon_0} \frac{e^2}{2nh}.$$

Bohr radius:

$$r_1 = \epsilon_0 \frac{h^2}{\pi m e^2}.$$

principal quantum number: the value n for each orbit; used in specifying the state of atom.

Relation of the Rydberg constant to fundamental constants

$$hcR = \frac{1}{\epsilon_0^2} \frac{m e^4}{8 h^2}, \quad \text{or} \quad R = \frac{m e^4}{8 \epsilon_0^2 h^3 c}.$$

From this equation, we can calculate the vale of the Rydberg constant R from the fundamental constants m, c, e, h, and ϵ_0, all of which can be determined independently of the Bohr theory.

ionization energy: energy required to remove the electron completely from a hydrogen atom; in general the energy required to remove *an* electron from an atom. Backscattering xray machines used in airports to produce security images use ionizing radiation.

3.1   Links

EPA: Health effects of Ionizing Radiation
International Atomic Energy Agency: Effects of Radiation (pdf)

4 The Laser

laser: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation; a light source that produces a beam of highly coherent very nearly monochromatic light as a result of "cooperative' emission from many atoms.
spontaneous emission: when a ground state atom absorbs a photon, becomes excited, and returns to ground state by emitting a photon with the same frequency and energy as the one originally absorbed.
stimulated emission: an incident photon encounters an atom that's already in an excited state with the same energy above the ground state as the photon's energy; by a kind of resonance effect, the incoming photon causes the atom to emit another photon with the same frequency and direction as the incoming photon, with its vibrations synchronized with those of the incoming photon.
population: the number n_E of atoms in a particular state.
population inversion: when n_E is substantially increased compared with its normal equilibrium value.

5 X-Ray Production and Scattering

x rays: a product of rapidly moving electrons accelerated through a potential difference on the order of 10^3 to 10^6 V striking a metal target.
x ray energy levels: the set of atomic energy levels associated with x-ray photons; different from visible spectra.
Compton scattering:when w rays strike matter, some of the radiation is scattered and some of this radation has a smaller frequency and longer wavelength than the incident radiation; the increase in wavelength is $\Delta\lambda$ and depends on the angle through which the radiation is scattered.

Wavelength increase in Compton scattering

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{mc}\left(1 - \cos\phi\right),$$

where m is the electron mass.

Mathematica Demonstrations: Compton Effect

6 The Wave Nature of Particles

De Broglie wavelength of an electron

$$\lambda = \frac{h}{p} = \frac{h}{m\nu},$$

where h is Planck's constant.

Davisson-Germer Experiment: atoms in a crystal form a lattice which behaves like a three-dimensional grating to incident x-rays creating constructive interference.
electron diffraction: angles at which strong reflection take place are the same as those at which x rays with the same wavelength would be reflected.

7 WaveParticle Duality

Heisenberg uncertainty principle for position and momentum

$$\Delta x \Delta p_x \geq \frac{h}{2\pi}.$$

Heisenberg uncertainty principle for energy and time

The uncertainty of ΔE in the energy of a system in a particular state depends on the time interval Δt during which the system remains in that state. The relation is

$$\Delta E \Delta t \geq \frac{h}{2\pi}.$$

A system that remains in a certain state for a long time (large Δt) can have a well-defined energy (small ΔE), but if it remains in that state for only a short time (small $Delta t$), the uncertainty in energy must be correspondingly greater (large ΔE).

Mathematical Demonstrations: Wave Particle Duality

8 The Electron Microscope

electron microscope: an electron beam can be used to form an image of an object just as a light beam; light microscopes use reflection and refraction; electron microscopes use electromagnetic fields.

9   Links

More on Wave-Particle Duality and Uncertainty from Feynman: Cornell, Feynman, 1964