



WPM03 RUTHERFORD'S MODEL & ATOMIC ABSORPTION

SPH4U

CH 12 (KEY IDEAS)

- define and describe the concepts and units related to the present-day understanding of the nature of the atom
- describe the photoelectric effect in terms of the quantum energy concept
- outline evidence that supports a photon model of light
- describe and explain the Bohr model of the hydrogen atom
- collect or interpret experimental data involving the photoelectric effect and the emission spectrum of hydrogen
- outline the historical development of models of matter and energy from 1890 to 1925
- describe how the development of quantum theory has led to scientific and technological advances
- describe some Canadian contributions to modern physics

EQUATIONS

- Photon Emission

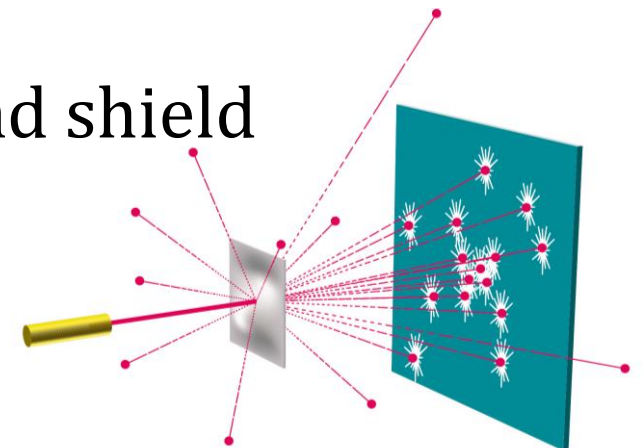
$$E_p = E_i - E_f$$

- Photon Absorption

$$E_p = E_f - E_i$$

THE RUTHERFORD EXPERIMENT

- We can explore the distribution of mass of a substance by shooting particles through it and seeing how the speed and direction have changed when they pass through
- Rutherford proposed shooting α particles (${}^4_2\text{He}^{2+}$) emitted by decaying polonium at a very thin (10^{-7} m, about 400 atoms) sheet of gold foil
 - The locations were controlled using holes in a lead shield
- A scintillation screen was used to count the scattered particles

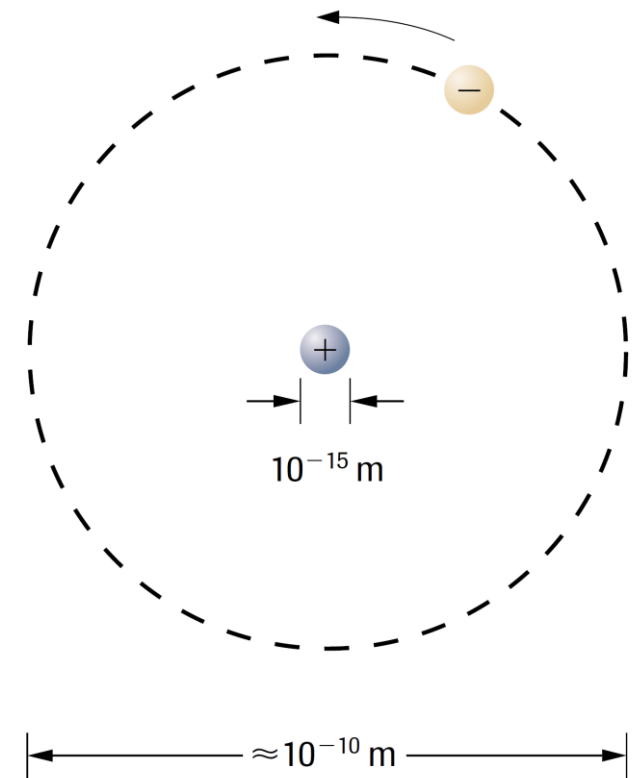


THE RUTHERFORD EXPERIMENT – CONT.

- Geiger and Marsden performed their scattering experiments, finding the following.
 1. The great majority of a particles passed through the gold foil with virtually no deviation from their original path.
 2. Very few a particles were scattered through sizable angles (with only 1 in 10 000 deflected by more than 10°).
 3. In extremely rare cases, an a particle was deflected by nearly 180° , back along its original path.
 4. After a period of exposure to the beam, the foil acquired a positive charge.

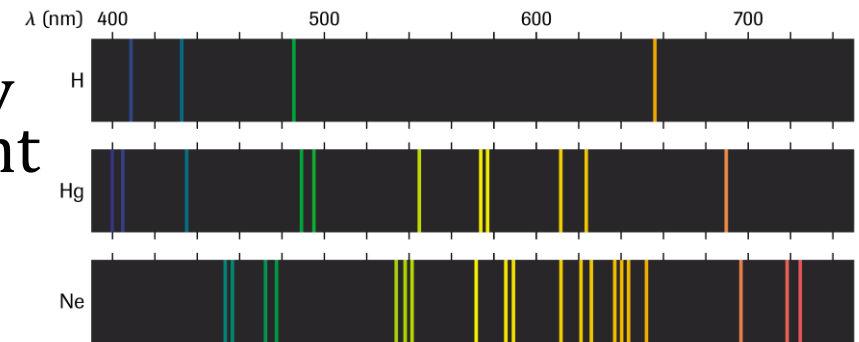
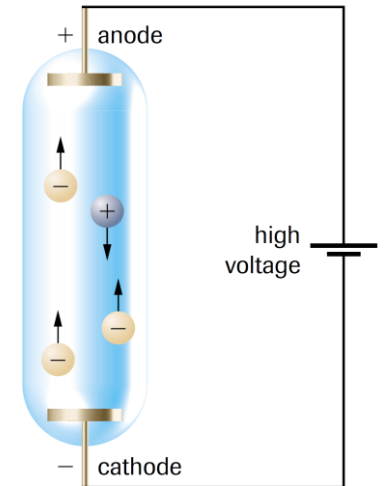
THE RUTHERFORD EXPERIMENT – CONT.

- Rutherford interpreted these results and deduced the following
 1. The greatest proportion of an atom's volume is empty space.
 2. The atom has a positively charged, very small but extremely dense central region—the nucleus—containing all of the atom's positive charge and most of its mass.
 3. The greatest proportion of an atom's volume is empty space and, within this empty space, a number of very light, negatively charged electrons move in orbits around the nucleus.



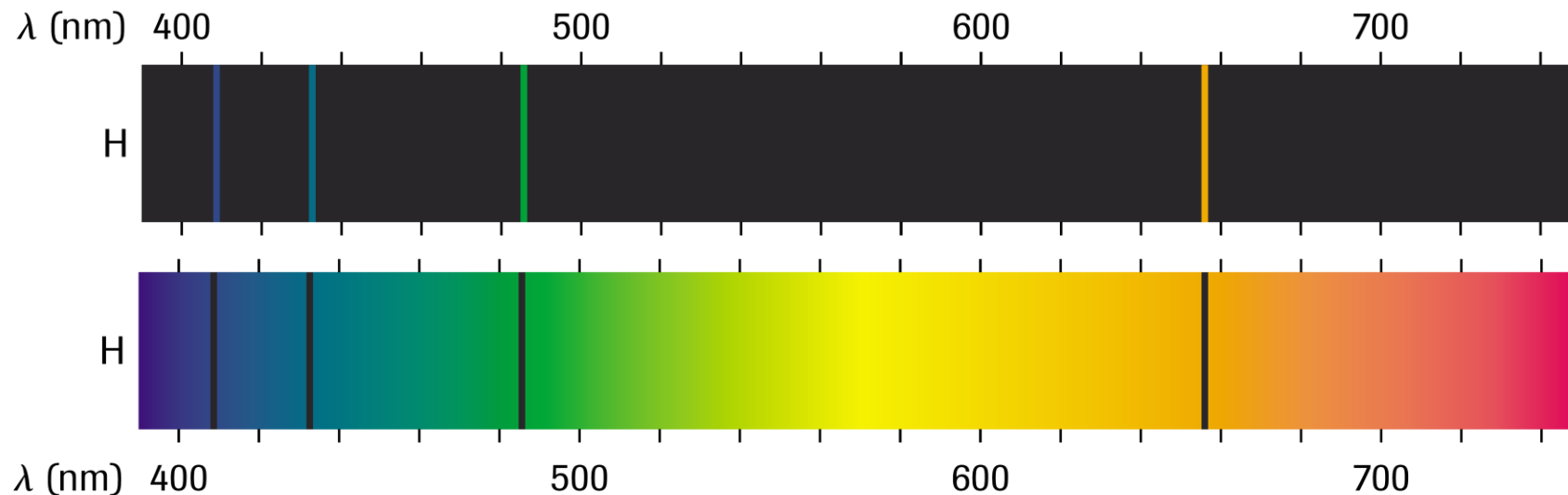
ATOMIC ABSORPTION AND EMISSION SPECTRA

- **Continuous Spectrum:** a spectrum showing continuous (not discrete) changes in intensity
 - White light, emitted from heated solids resulting from interactions between closely packed atoms
- **Emission Spectrum:** a spectrum that a substance emits with its own specific set of characteristic frequencies
 - Hot, rarified gasses are spread out, emitting light from individual atoms
 - Allows for spectroscopy to accurately identify elements, usually sending an electrical current through a tube of rarified gas



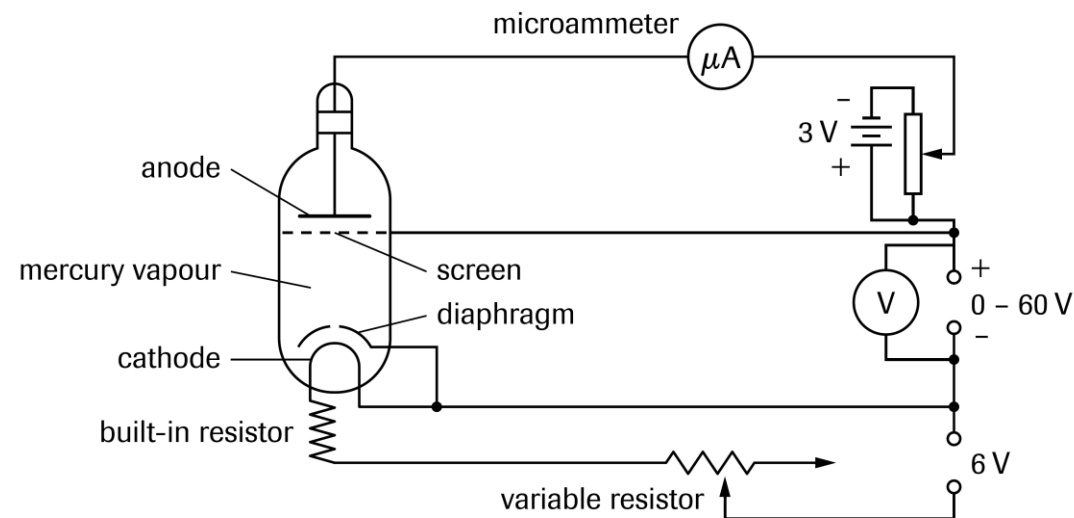
ATOMIC ABSORPTION AND EMISSION SPECTRA – CONT.

- **Absorption Spectrum:** the lines of missing colour in a continuous spectrum, at the same frequencies as would be emitted by an incandescent gas of the same element



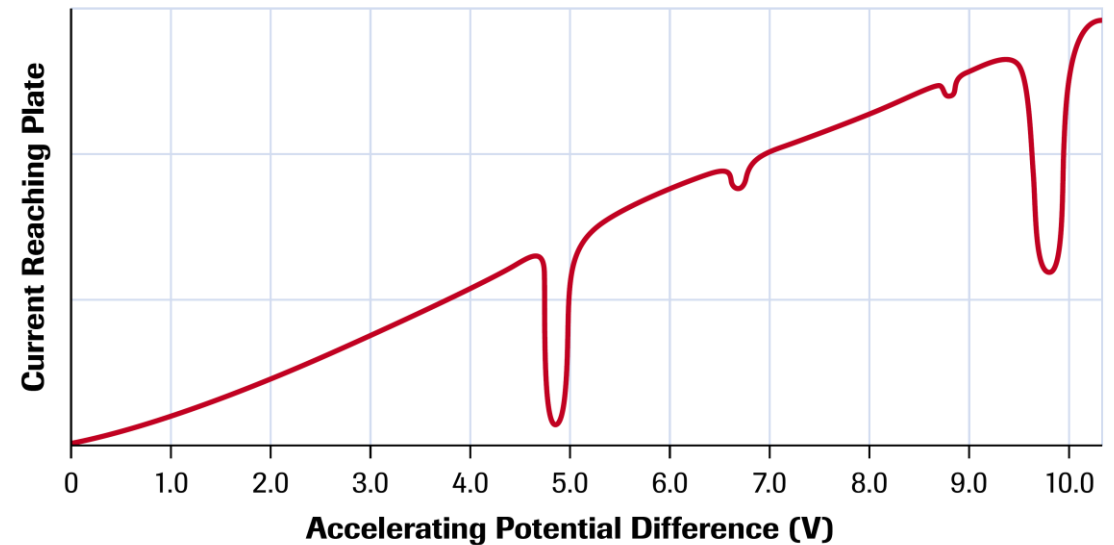
THE FRANCK-HERTZ EXPERIMENT

- Electrons emitted by a cathode were accelerated through mercury mist by a wire screen anode
- Most electrons passed through the grid, read as current by a sensitive microammeter



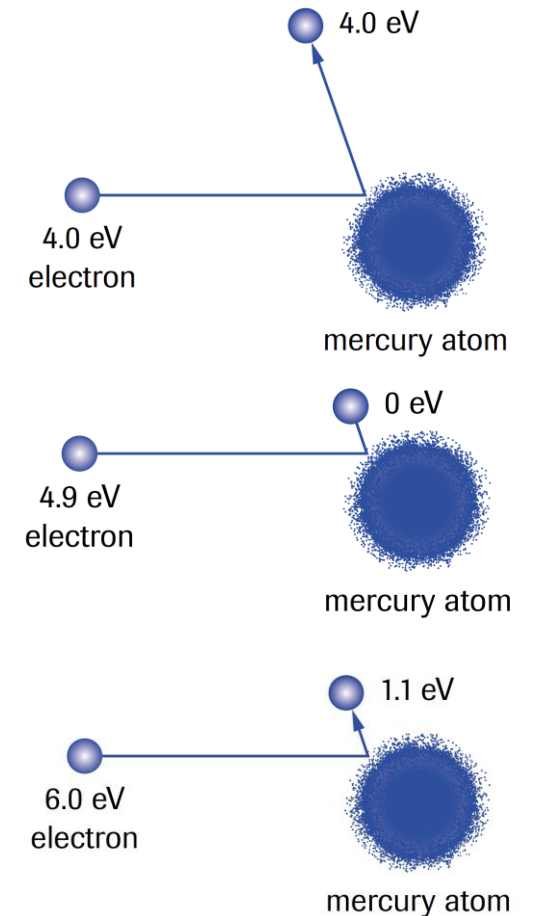
THE FRANCK-HERTZ EXPERIMENT – CONT.

- As the accelerating potential difference was increased slowly from zero, the current increased gradually as well.
- At a potential of 4.9 V, the current dropped dramatically, almost to zero.
- As the potential was increased further, the current once again began to increase.
- Similar but minor decreases in current occurred at potentials of 6.7 V and 8.8 V.
- Another significant decrease in current occurred at a potential of 9.8 V.



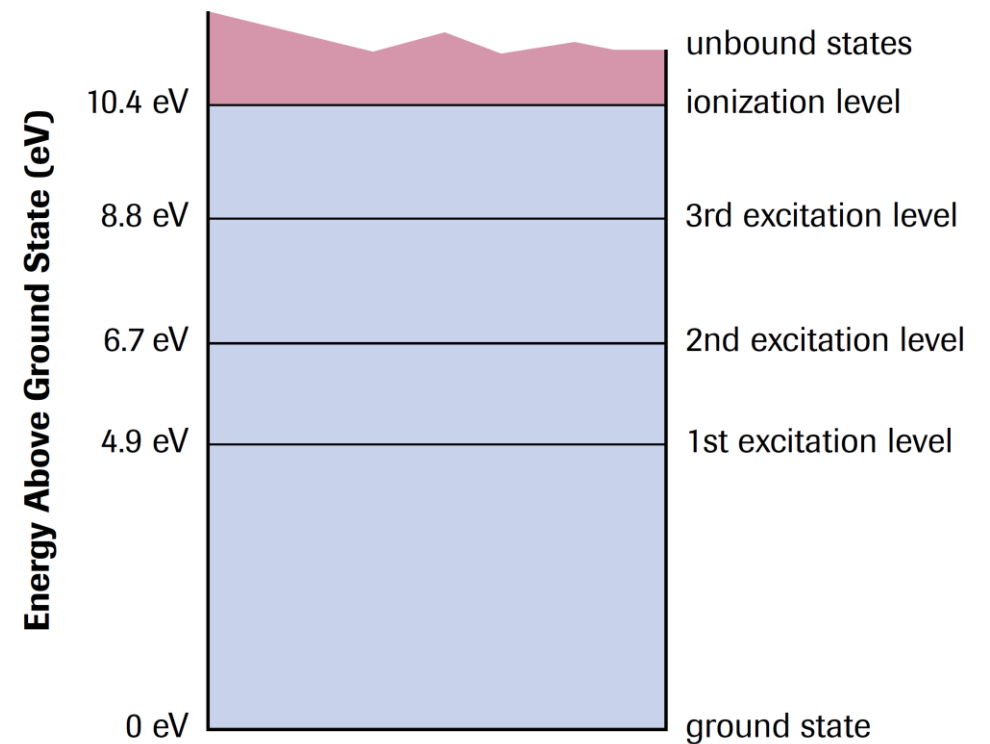
THE FRANCK-HERTZ EXPERIMENT – CONT.

- Electrons with $E_K < 4.9$ eV had elastic collisions with the mercury atom and did not transfer any kinetic energy
- Electrons with $E_K = 4.9$ eV had completely inelastic collisions transferred all kinetic energy to the mercury atom
- Electrons with $E_K > 4.9$ eV transferred 4.9 eV to the mercury atom
- Electrons with $E_K = 9.8$ eV had two completely inelastic collisions
- Similar patterns occurred with 6.7 eV and 8.8 eV, but less frequently



THE FRANCK-HERTZ EXPERIMENT – CONT.

- **Ground State:** the lowest energy state of an atom
- **First Excitation Energy:** the smallest amount of energy an atom is capable of absorbing
- **Energy Levels:** the various discrete values of internal energy that an atom can possess
- **Ionization Energy:** the energy required to liberate an electron from an atom



PROBLEM 1

Electrons with a kinetic energy of 12.0 eV collide with atoms of metallic element X, in the gaseous state. After the collisions, the electrons are found to emerge with energies of 4.0 eV and 7.0 eV only. What are the first and second excitation levels for atoms of element X?

PROBLEM 1 – SOLUTIONS

Since energy is conserved in the interaction between a free electron and an electron bound to an atom in its ground state,

$$E_n = E_{K,\text{initial}} - E_{K,\text{final}}$$

$$E_1 = 12.0 \text{ eV} - 7.0 \text{ eV} = 5.0 \text{ eV}$$

$$E_2 = 12.0 \text{ eV} - 4.0 \text{ eV} = 8.0 \text{ eV}$$

The first and second excitation levels are 5.0 eV and 8.0 eV, respectively.

ANALYSING ATOMIC SPECTRA

- In general, for the emission spectrum of any element, we can write

$$E_p = E_i - E_f$$

- E_p – energy of the emitted photon [eV]
 - E_i – energy of the higher energy level [eV] (sometimes E_h)
 - E_f – energy of the lower energy level [eV] (sometimes E_l)
- To solve for wavelength, an adjustment of Planck's equation is

$$\lambda = \frac{hc}{E_p} = \frac{hc}{E_i - E_f}$$

PROBLEM 2

An unknown substance has first and second excitation levels of 3.65 eV and 5.12 eV, respectively. Determine the energy and wavelength of each photon found in its emission spectrum when the atoms are bombarded with electrons of kinetic energy (a) 3.00 eV, (b) 4.50 eV, and (c) 6.00 eV.

PROBLEM 2 – SOLUTIONS

- (a) Since the first excitation energy is 3.65 eV, no energy is absorbed, and there is no emission spectrum.

PROBLEM 2 – SOLUTIONS

(b) With incident electrons of energy 4.50 eV, only upward transitions to the first excitation level are possible.

$$E_p = ?$$

$$\lambda = ?$$

$$\begin{aligned} E_p &= E_i - E_f \\ &= 3.65 \text{ eV} - 0 \text{ eV} \end{aligned}$$

$$E_p = 3.65 \text{ eV}$$

$$\begin{aligned} \lambda &= \frac{hc}{E_p} \\ &= \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})(3.00 \times 10^8 \text{ m/s})}{(3.65 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})} \end{aligned}$$

$$\lambda = 3.41 \times 10^{-7} \text{ m or } 341 \text{ nm}$$

The energy and wavelength of each photon are 3.65 eV and 341 nm, respectively.

PROBLEM 2 – SOLUTIONS

(c) With incident electrons of energy 6.00 eV, excitation to both the first and second levels is possible. Thus, in addition to the photon emitted in (b), we can have

$$\begin{aligned} E_p &= E_h - E_l & \text{and} & & E_p &= E_h - E_l \\ &= 5.12 \text{ eV} - 0 \text{ eV} & & & &= 5.12 \text{ eV} - 3.65 \text{ eV} \\ E_p &= 5.12 \text{ eV} & & & E_p &= 1.47 \text{ eV} \end{aligned}$$

The energies of the photons are 1.47 eV and 5.12 eV. The wavelengths, calculated with the same equation as in (b), are 243 nm and 846 nm, respectively. (None of these photons would be visible to the naked eye because one is infrared and the other two are ultraviolet.)

ANALYSIS OF ABSORPTION SPECTRA

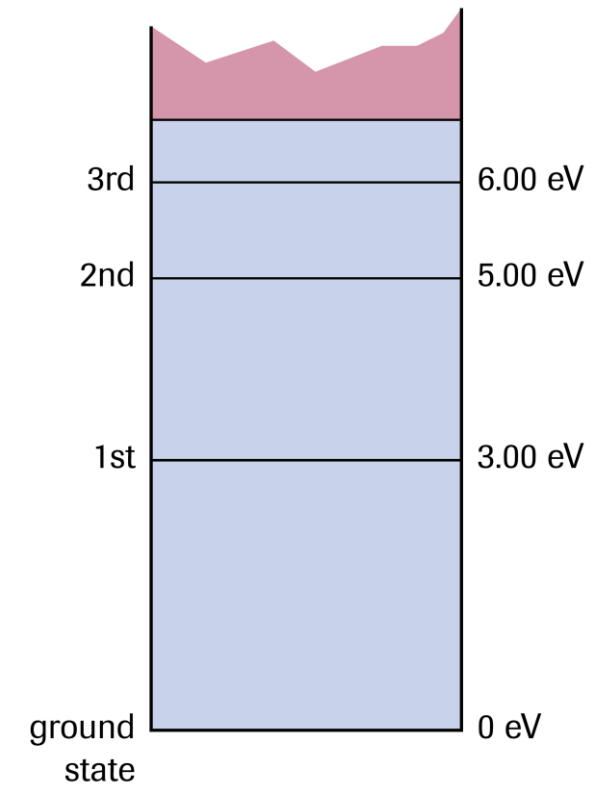
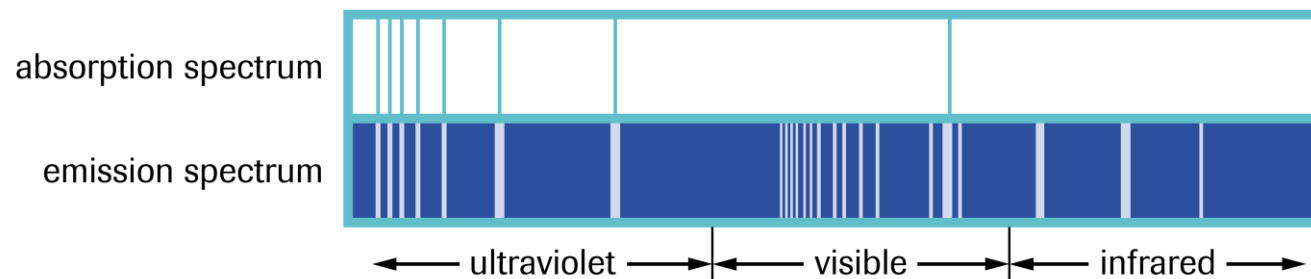
- The equation for absorption is the opposite to that of emission

$$E_p = E_f - E_i$$

- E_p – energy of the emitted photon [eV]
- E_f – energy of the lower energy level [eV] (sometimes E_l)
- E_i – energy of the higher energy level [eV] (sometimes E_h)

ANALYSIS OF ABSORPTION SPECTRA – CONT.

- Emissions spectrums will show more lines than absorption spectrums
 - Drops between different energy levels occur with emissions spectrums
 - Absorption only occurs with elements in their ground state



FLUORESCENCE AND PHOSPHORESCENCE

- **Fluorescence:** the process of converting high-frequency radiation to lower-frequency radiation through absorption of photons by an atom
 - When the light source is removed, the fluorescence stops
 - Colour of radiation depends on energy levels of the atoms
- **Phosphorescence:** the property of some materials that allows them to emit light after excitation has been removed
 - **Metastable:** state of sustained excitation by electrons in which they can remain excited for comparatively long times

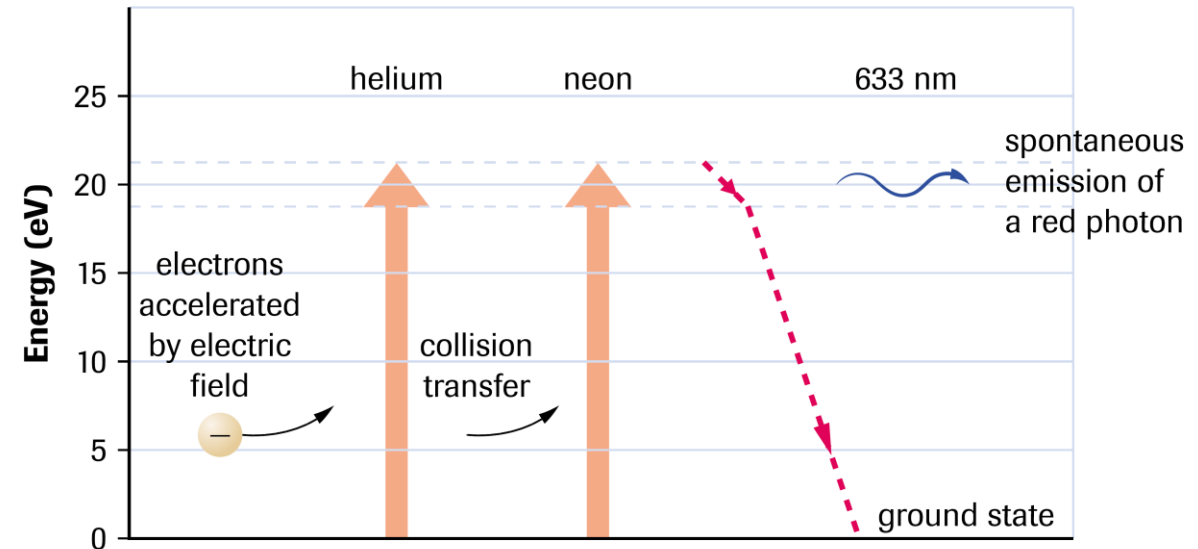
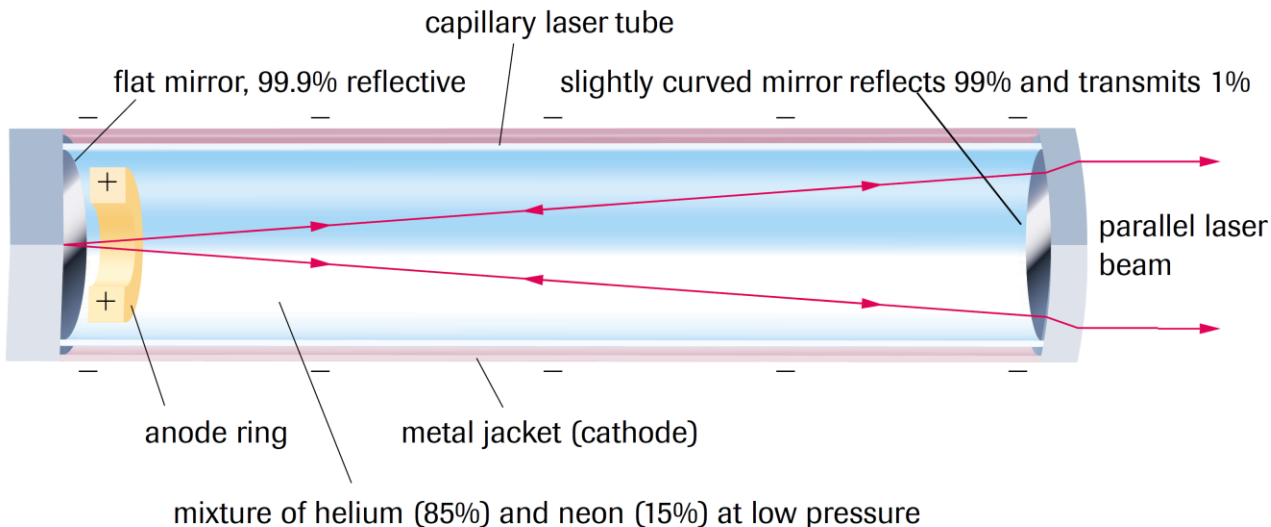
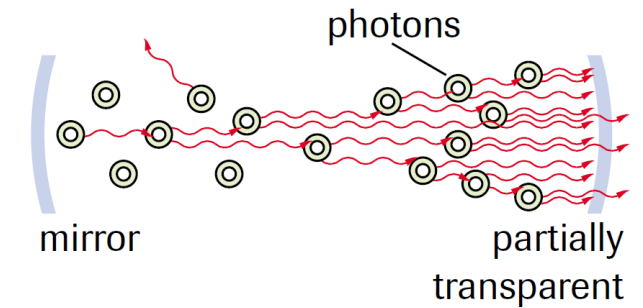
LASERS

- **Laser:** acronym for Light Amplification by Stimulated Emission of Radiation; source of monochromatic, coherent light
- **Spontaneous Emission:** emission of a photon by an electron as a result of the absorption of a quantum of energy by an atom; the electron moves spontaneously to a lower energy level in a relatively short time ($\sim 10^8$ s)
- **Stimulated Emission:** process in which an excited atom is stimulated to emit a photon identical to a closely approaching photon
- **Coherence:** property of light in which photons have the same frequency and polarization, travel in the same direction, and are in phase
- **Population Inversion:** the condition in which more atoms are in a metastable state than in the ground state

LASERS – CONT.

- Continuous Laser

- Helium-neon laser
- Electrons transfer energy to He, which transfer energy to Ne through collisions
- Ne releases photons when returning to ground state
- Mirrors help amplify the particles, allowing a partial transmission of photons



LASERS – CONT.

- Pulse Laser
 - Atoms are excited by periodic inputs of energy, after which they are stimulated to fall to a lower state
 - The process then recycles, with another input of excitation energy.

SUMMARY – RUTHERFORD'S MODEL OF THE ATOM

- The α -scattering experiment revealed that the great majority of a particles passed straight through the gold foil; only a few a particles were scattered by sizable angles; a very few were deflected by 180° .
- Rutherford's model proposed that the atom consists of a small, extremely dense positive nucleus that contains most of its mass; the atom's volume is mostly empty space; and the Coulomb force holds the electrons in orbit.
- Further work on a scattering revealed that Coulomb's law, $F_e = \frac{kq_1q_2}{r^2}$, applies to the electric force between small charged particles even at distances smaller than the size of atoms; the positive charge on the nucleus is the same as the atomic number.

SUMMARY – ATOMIC ABSORPTION AND EMISSION SPECTRA

- A continuous spectrum given off by a heated solid is caused by the interactions between neighbouring atoms or molecules. An emission spectrum or line spectrum is emitted from electrically “excited” gases.
- An absorption spectrum occurs when some of the light from a continuous spectrum is absorbed upon passing through a gas. Atoms absorb light of the same frequencies that they emit.
- The Franck–Hertz experiment showed that the kinetic energy of incident electrons is absorbed by mercury atoms but only at discrete energy levels.
- An atom is normally in its ground state. The excited states or energy levels are given by the discrete amounts of energy the atom can internally absorb.
- Ionization energy is the maximum energy that can be absorbed internally by an atom, without triggering the loss of an electron.
- In the emission spectrum, the energy of the emitted photon equals the change in the internal energy level: $E_p = E_i - E_f$.
- When a photon is absorbed, its energy is equal to the difference between the internal energy levels: $E_p = E_f - E_i$.
- Atoms can receive energy in two ways: by collisions with high-speed particles, such as electrons, and by absorbing a photon.
- Once raised to an excited state, an atom can emit photons either through spontaneous emission or through stimulated emission. Light amplification requires stimulated emission.
- Some substances or combinations of substances have metastable excited states. A population inversion occurs when more atoms are in a metastable condition than in the ground state.
- For laser action to take place, both population inversion and the conditions for stimulated emission must exist in the lasing medium.
- Lasers are of two types: continuous and pulsed.



PRACTICE

Readings

- Section 12.3 (pg 621)
- Section 12.4 (pg 626)

Questions

- pg 625 # 1,2
- pg 638 # 1,2,8