CHEM110 – Chapter 4
Atomic Energy Levels

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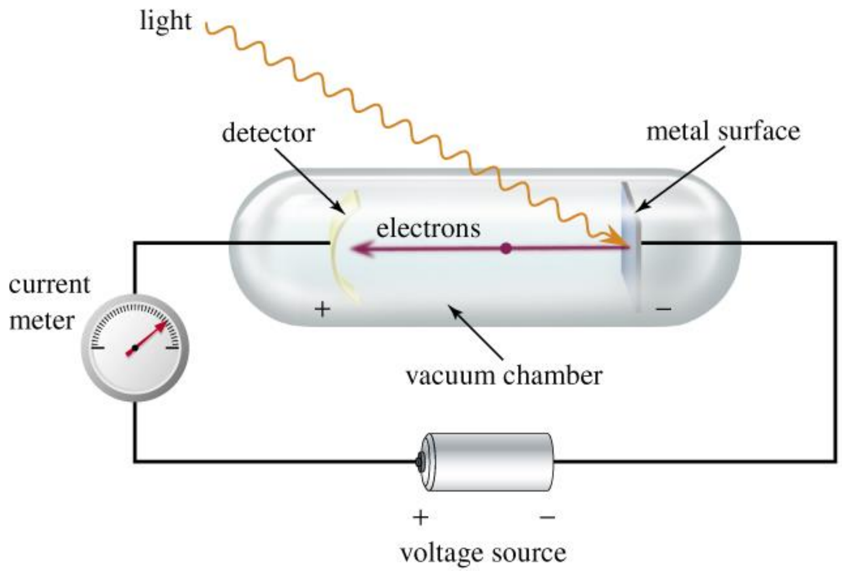
4.2 Characteristics of Light

- **Light carries energy → the photoelectric effect (page 112) shows how the energy of light depends on its frequency**
- **Light causes electrons to be ejected from the metal surface**



Threshold Frequency → ν_0

- **Different ν_0 for different metals**

4.2 Characteristics of Light

Albert Einstein postulated that light comes in ‘packets’ or ‘bundles’ → photons

4.2 Characteristics of Light

- **Each photon has an energy that is directly proportional to its frequency**

$$E_{photon} = h\nu_{photon}$$

h (Planck's constant) = 6.626×10^{-34} J s

4.2 Characteristics of Light

- **Energy of a photon with the threshold frequency (ν_0) corresponds to the binding energy of an electron**
- **Electron kinetic energy = photon energy – binding energy**

$$E_{\text{kinetic(electron)}} = h\nu - h\nu_0$$

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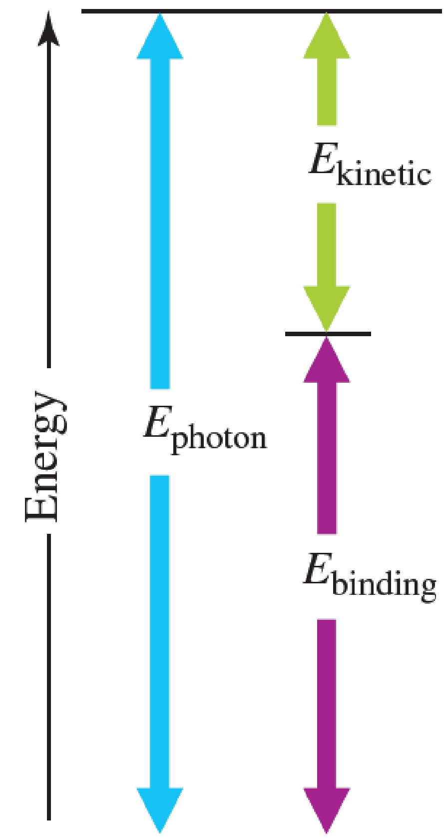
4.2 Characteristics of Light

Diagram of the energy balance for the photoelectric effect



$$E_{kinetic(electron)} = h\nu - h\nu_0$$

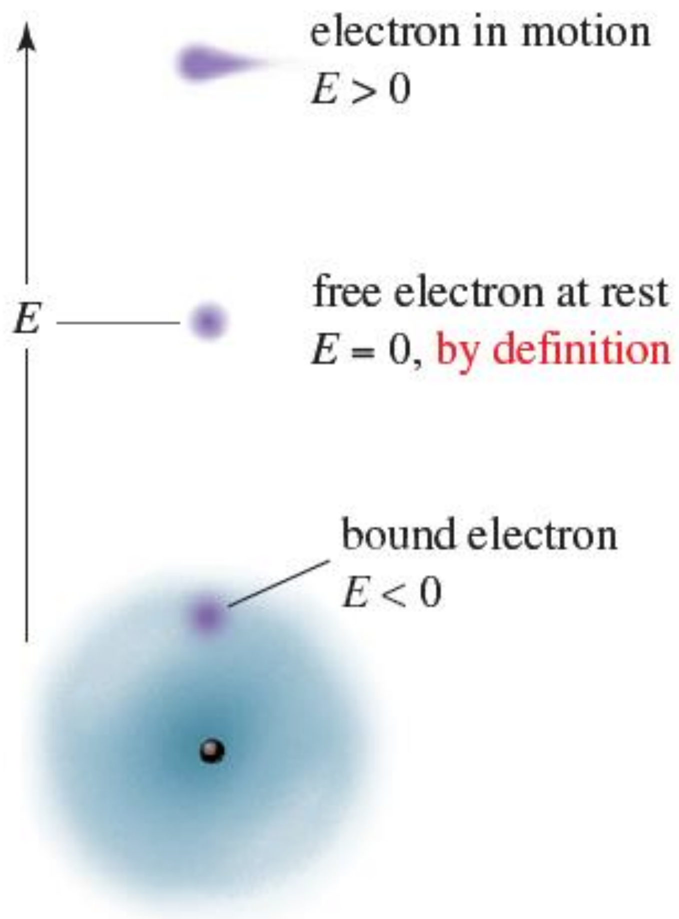
A complete description of light includes both wave-like and particle-like properties

4.2 Characteristics of Light

- **Light strikes metal → energy absorbed tells us about the binding energy of electrons**

- **Light interacts with free atoms → energy absorbed tells us about electrons on individual atoms**

4.2 Characteristics of Light



- Bound electron → electrostatic forces
- Energy required to remove the electron
- Lower the atoms energy state → more energy required to remove electron

4.2 Characteristics of Light

- **Absorption of photon by free atom → two possible outcomes:**

1. **Electron ejected → ionization**

2. **Electron gains energy but does NOT ionize**

4.2 Characteristics of Light

- Ground state → lowest energy state of an atom
- Excited state → when an atom absorbs a photon

4.2 Characteristics of Light

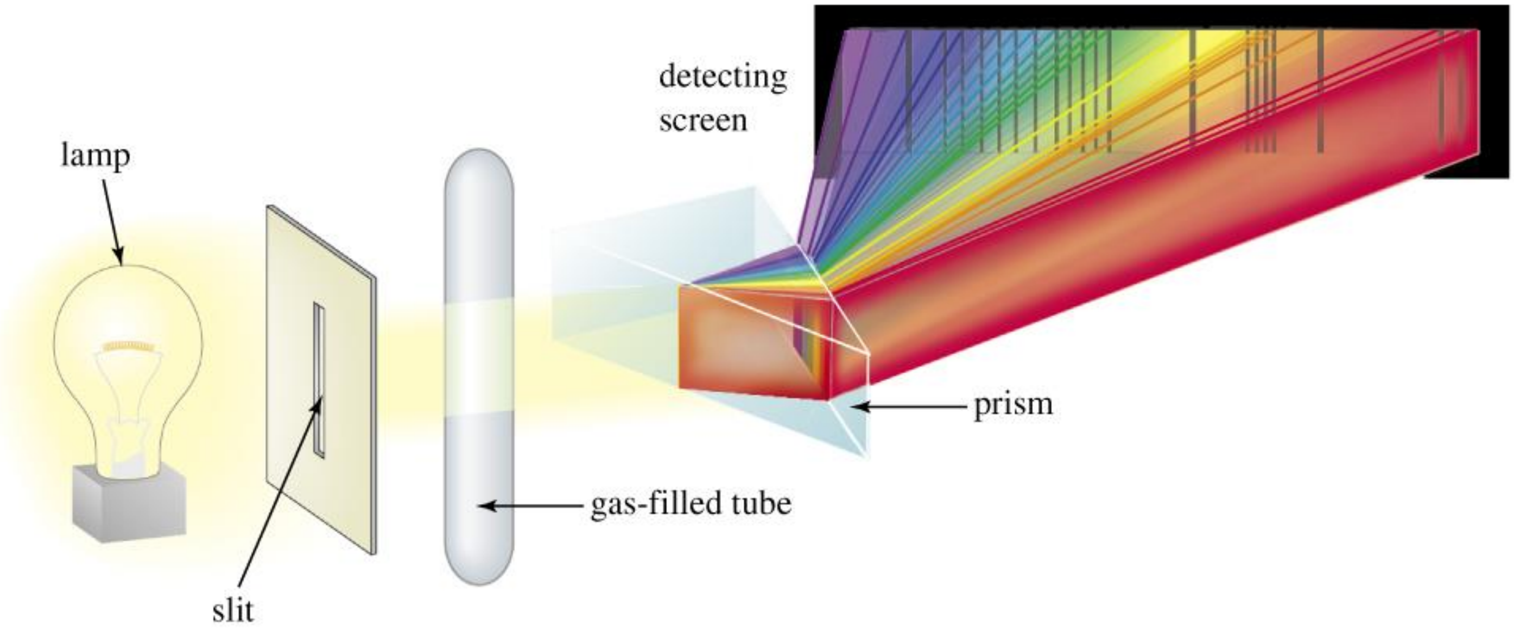
- Returns to the ground state → emits a photon or collides with another atom

- Energy is conserved

- $\Delta E_{\text{atom}} = \pm\, h\nu_{\text{photon}}$

4.2 Characteristics of Light

Absorption → atoms absorb specific and characteristic frequencies of light



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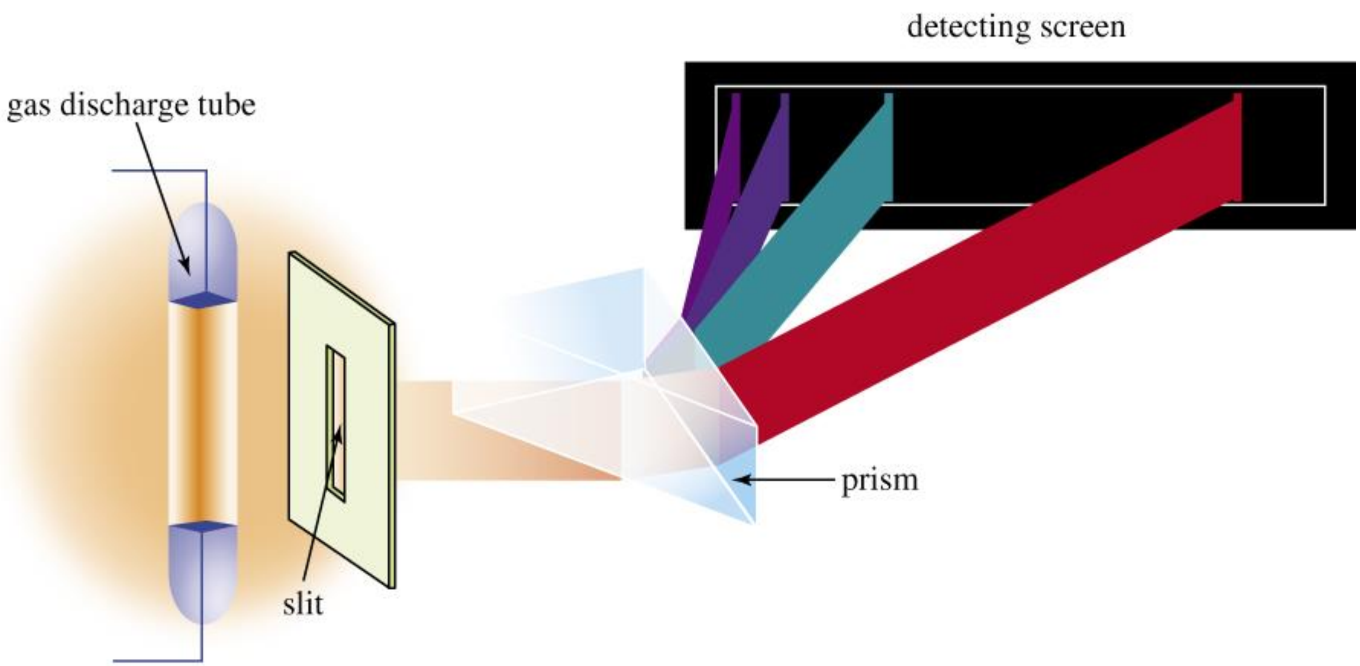
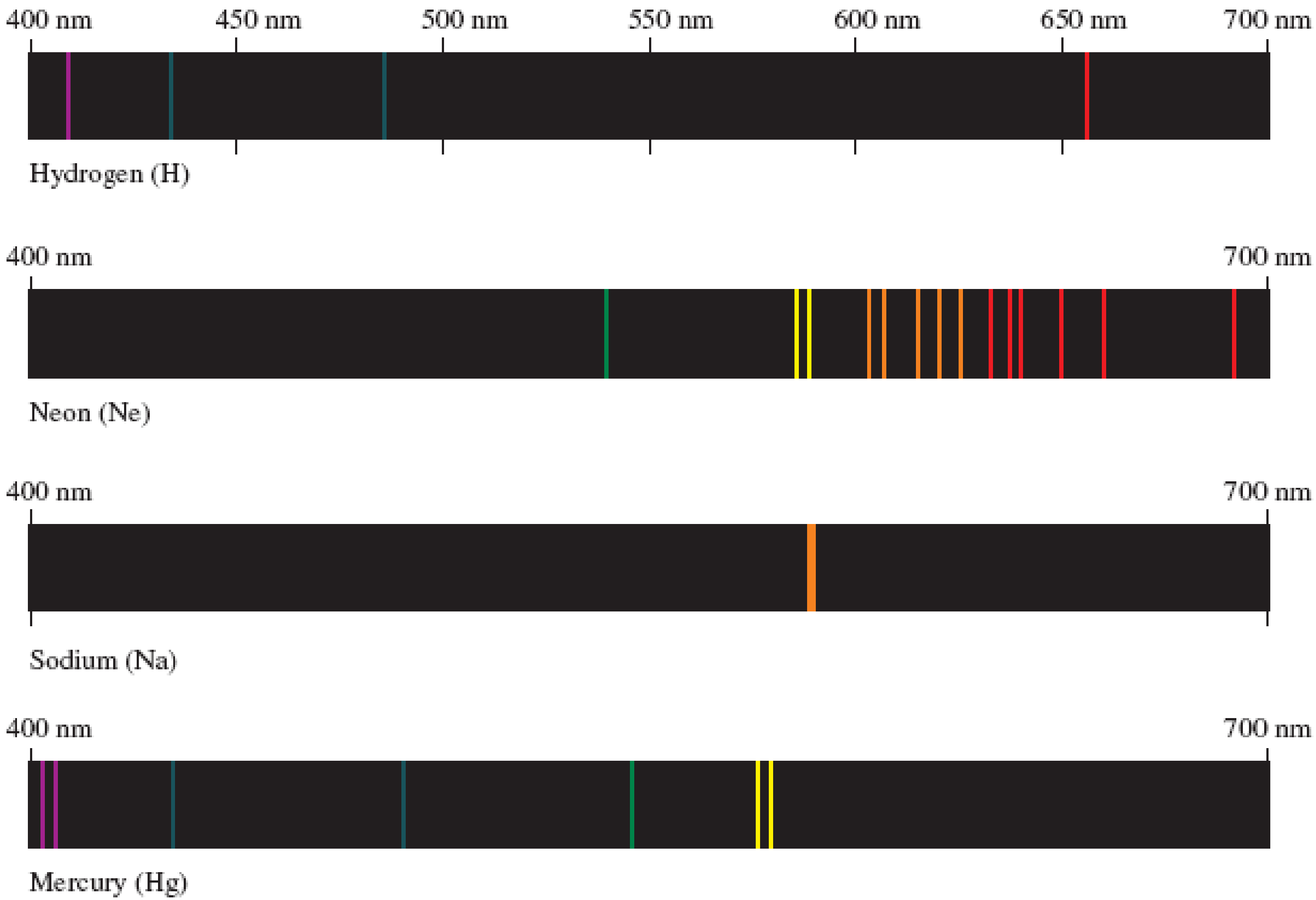
4.2 Characteristics of Light

Emission → photons are emitted by atoms in excited state



4.2 Characteristics of Light



4.2 Characteristics of Light

Each element has unique absorption and emission spectra → provides information about atomic structure

4.2 Characteristics of Light

- **A photon with high enough energy can cause an atom to lose one of its electrons**
- **Implies that absorption of a photon results in an energy gain for an electron**

$$\Delta E_{\mathrm{atom}} = \Delta E_{\mathrm{electron}} = h\nu$$

4.2 Characteristics of Light

- Emission frequencies have specific values because the electron is restricted to specific energies
- Quantised

$$\Delta E_{\mathrm{atom}} = E_{\mathrm{final}} - E_{\mathrm{initial}}$$

$$E_{\mathrm{photon}} = \left|\Delta E_{\mathrm{atom}}\right|$$

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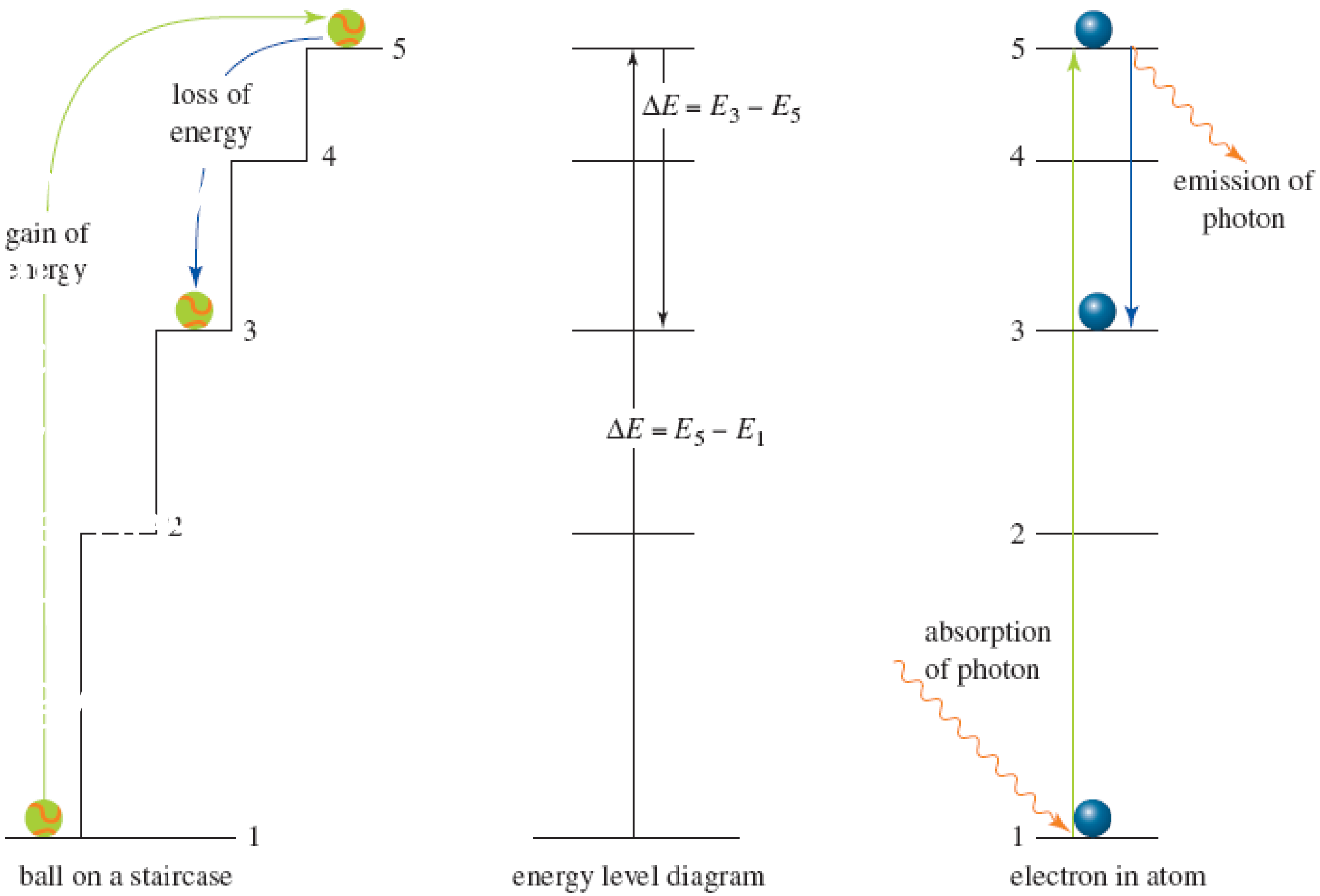
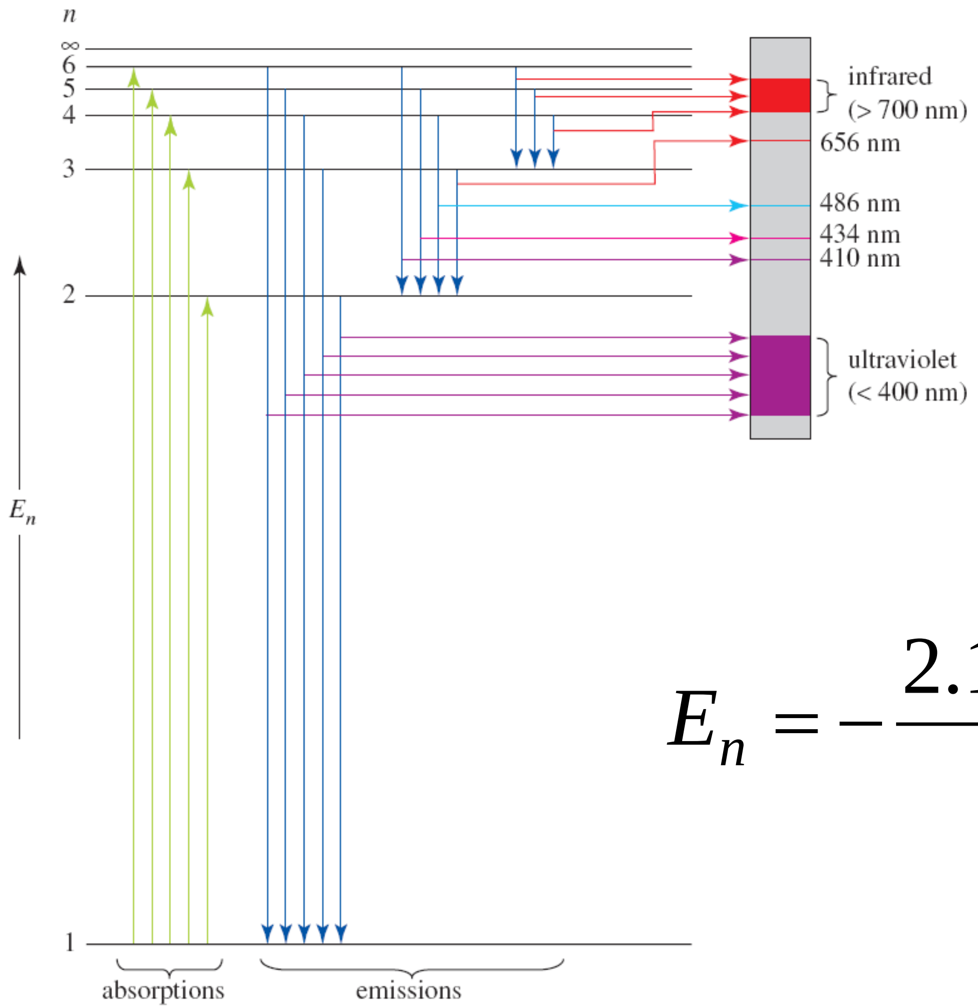
4.2 Characteristics of Light

Figure 4.21



4.2 Characteristics of Light

Figure 4.22



$$E_n = -\frac{2.18\times10^{-18}\ \mathrm{J}}{n^2}$$

4.3 Properties of Electrons

- **Electrons all have the same mass and charge**
- **They have magnetic properties (spin)**
- **Louis de Broglie suggested the wave-particle duality for electrons**

$$\boxed{\lambda_{\text{particle}} = \frac{h}{mu}}$$

4.3 Properties of Electrons

Photons and electrons have wave and particle properties

Property	Photon equation	Electron equation
energy	$E = h\nu$	$E_{\text{kinetic}} = \frac{1}{2} mu^2$
wavelength	$\lambda = \frac{hc}{E}$	$\lambda = \frac{h}{mu}$
speed	$c = 2.998 \times 10^8 \text{ m s}^{-1}$	$u = \sqrt{\frac{2E_{\text{kinetic}}}{m}}$

h: Planck's constant; ν: frequency; m: mass; u: velocity

4.3 Properties of Electrons

- Particles occupy a location but a wave has **no exact position** → waves extend over some **region of space**
- Electrons are spread out rather than located in one particular place
- Position of a moving electron cannot be precisely defined!
- Electrons described as being **delocalized**

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4.3 Properties of Electrons

- **Mathematically → the position and momentum of a particle-wave are linked**
- **Heisenberg showed that position and momentum of a particle-wave cannot be simultaneously determined**
- **The Heisenberg Uncertainty Principle states that the more accurately we know position, the more uncertain we are about motion, and vice versa**
- **So instead, we identify a 'probable location' of the electrons in an atom, not an exact one**

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Worked Example 4.4 – page 121

What is the energy change when the electron in a hydrogen atom undergoes a transition from the fourth energy level to the second energy level? What is the wavelength of the photon emitted?

$$\Delta E_{\text{atom}} = E_{\text{final}} - E_{\text{initial}} = E_2 - E_4$$

$$E_n = -\frac{2.18\times10^{-18}\ \text{J}}{n^2} \qquad E_{\text{photon}} = h\nu = \frac{hc}{\lambda}$$

Worked Example 4.7

Calculate the wavelengths of an electron travelling at 1.00 x 10^5 ms^{-1} and a table tennis ball with a mass of 11 g travelling at 2.5 ms^{-1}.

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