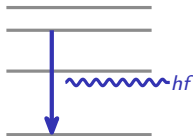


Modern Physics

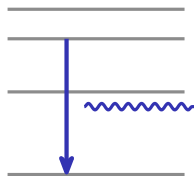
AP Physics 2 ■ Unit 15

AP Physics 2



What we will cover

- 1 Photons and wave-particle duality
- 2 The Bohr model and energy levels
- 3 Spectra and blackbody radiation
- 4 The photoelectric effect
- 5 Compton scattering
- 6 Nuclear physics





Photons and wave-particle duality

Light comes in packets called **photons** , each carrying:

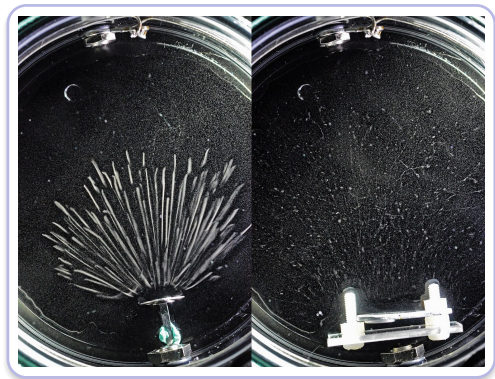
Photon energy

$$E = hf$$

Matter waves

$$\lambda = \frac{h}{p}$$

the **de Broglie wavelength** .



Particles leave tracks of ionisation

The evidence for duality

Double-slit experiment

The **double-slit experiment** gives interference fringes – and they build up one photon at a time, so each photon interferes with itself.

Photoelectric effect

Light behaving as particles: the electron's energy depends on the *frequency*, not the intensity.

Wave–particle duality

Wave–particle duality: which behaviour appears depends on what the apparatus asks. De Broglie extends it to matter, $\lambda = h/p$.

Absorption spectrum

An **absorption spectrum** is dark lines on a continuous background – the same energies the atom would emit, taken out on the way through.

Emission and absorption lines match exactly, which is what shows the energy levels are a property of the atom.



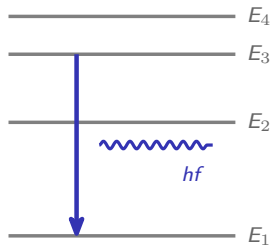
The Bohr model and energy levels

The **Bohr model** : electrons occupy only certain **energy levels** – energy is **quantized**.

A jump emits or absorbs a photon

$$E = hf = E_i - E_f$$

Hydrogen $-3.4 \rightarrow -13.6$ eV: emits a 10.2 eV photon.





Spectra and blackbody radiation

Discrete levels give sharp spectral lines – a **fingerprint** of each element:

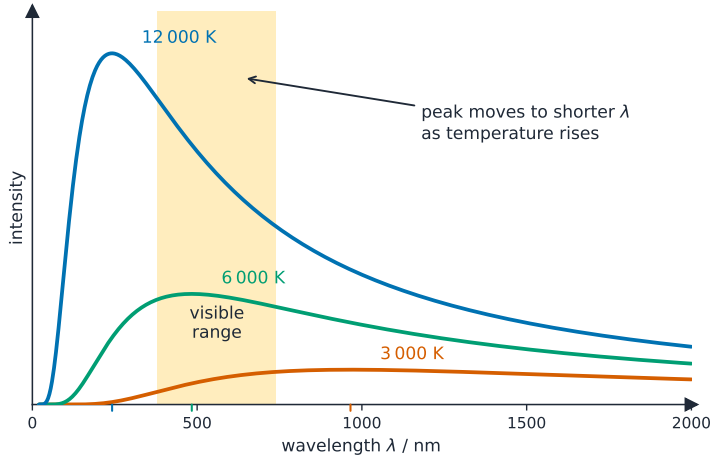
- **emission** : bright lines (electrons drop)
- **absorption** : dark lines in a rainbow (photons absorbed)

A hot **blackbody** glows across all wavelengths; hotter $\Rightarrow$ peak shifts to **shorter** λ (**Wien's law**).



Nuclear energy is released from the nucleus

A hotter black body radiates more



A hotter black body radiates more, and its peak shifts to shorter wavelengths



The photoelectric effect

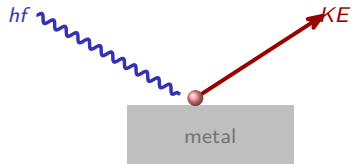
Light ejects electrons from a metal – only if each photon is energetic enough:

One photon, one electron

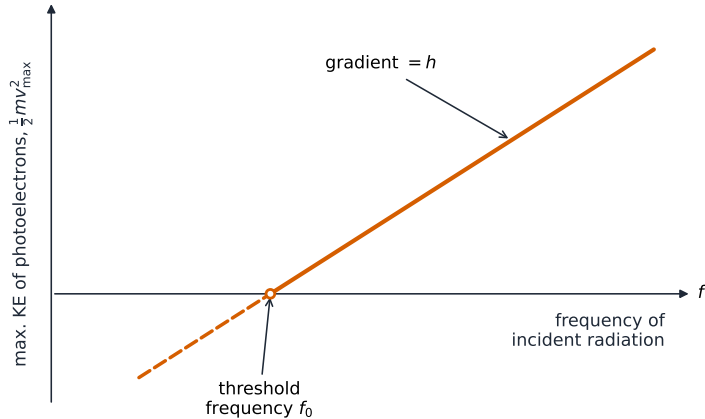
$$E = hf = \phi + KE_{max}$$

work function ϕ = energy to escape.

Below the **threshold frequency**, **no** electrons come out – however bright the light.



The maximum kinetic energy of photoelectrons rises



The maximum kinetic energy of photoelectrons rises linearly with frequency



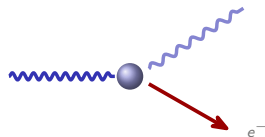
Compton scattering

A photon collides with an electron like two billiard balls – proof photons carry **momentum** :

Photon momentum

$$p = \frac{h}{\lambda}$$

The scattered photon loses energy, so it comes away with a **longer** wavelength. Both energy and momentum are conserved.





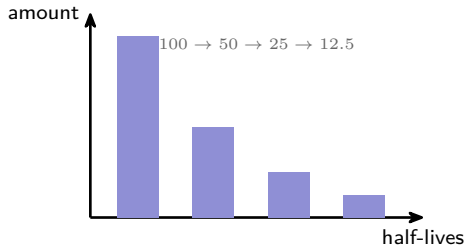
Nuclear physics

The nucleus releases huge energy when it changes – the lost **mass** becomes energy:

Mass-energy

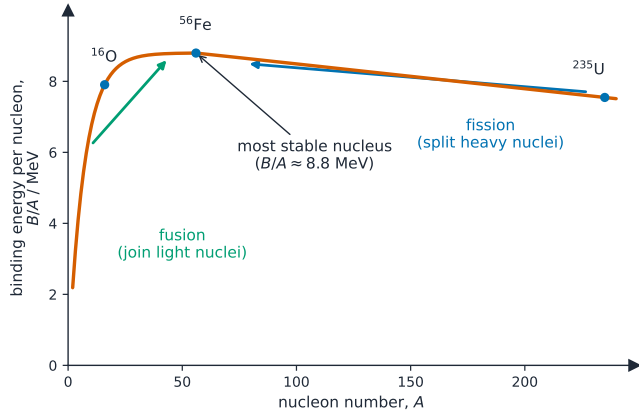
$$E = mc^2$$

- **fission** : split a heavy nucleus
- **fusion** : join light nuclei (the Sun)
- **alpha** / **beta** / **gamma** decay – conserve nucleons & charge



Half-life : time for half to decay.

Binding energy per nucleon peaks near iron



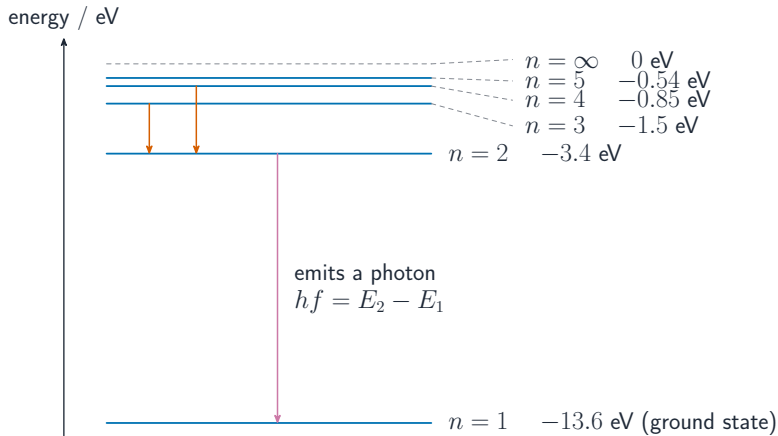
Binding energy per nucleon peaks near iron, so both fusion and fission can release energy

Emission and Absorption Spectra



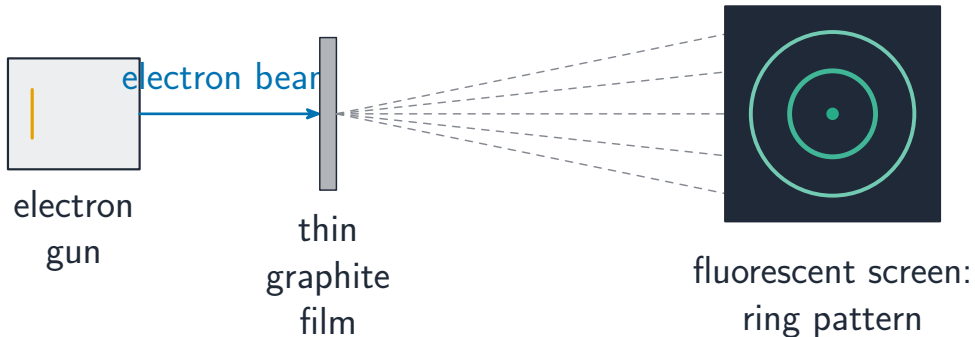
Hydrogen's emission spectrum: each bright line is light from an electron dropping between fixed energy levels

The discrete energy levels of hydrogen produce



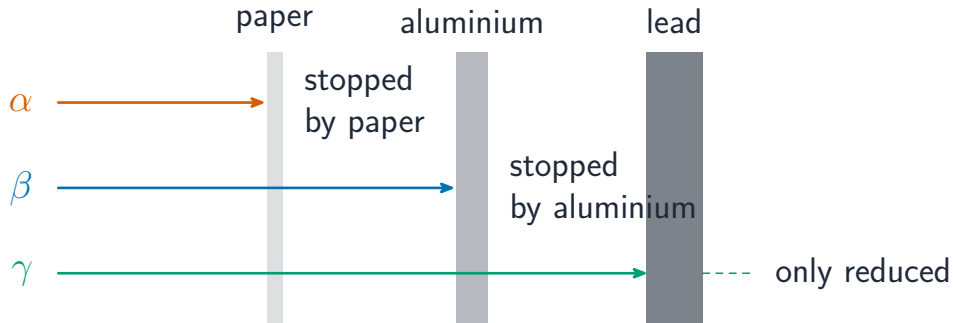
The discrete energy levels of hydrogen produce a line spectrum

Quantum Theory and Wave-Particle Duality



Electrons form a diffraction pattern, showing that particles have a wave nature

Types of Radioactive Decay



The penetrating power of alpha, beta, and gamma radiation

Photon energy, and the two nuclear routes

a photon's energy

$E = hf$ – so orange light at 5.0×10^{14} Hz carries 3.3×10^{-19} J, about 2.1 eV

quanta

light arrives in discrete packets, which is why the photoelectric effect has a threshold frequency

the nucleus

stores enormous energy

fission

splits a heavy nucleus into lighter ones, releasing energy

fusion

joins light nuclei into a heavier one, releasing more still

the conversion

$E = \Delta mc^2$: losing 1.0×10^{-3} kg releases 9.0×10^{13} J

Alpha decay α emits a helium nucleus; **beta decay** β a fast electron or a **positron** . Both change the nucleus; gamma emission does not.

Exam tips

- Photon energy is $E = hf$; below the **threshold frequency** no electrons are emitted **however bright** the light (the photoelectric effect).
- Use $K_{\text{max}} = hf - \phi$ for the fastest photoelectrons (ϕ = work function).
- Electrons jump between **discrete energy levels** by absorbing/emitting a photon whose energy equals the level gap – the source of line spectra.
- In fission and fusion the small **mass lost** becomes energy via $E = mc^2$.
- Balance decay equations by conserving **mass number, charge, and lepton number** (write the antineutrino in β^- , the neutrino in β^+), and halve the sample every **half-life** ($(\frac{1}{2})^n$ after n half-lives).



Unit 15 – key takeaways

1

Duality

$E = hf$, matter has $\lambda = h/p$; wave and particle both

2

Atoms

quantized levels; a jump gives
 $hf = E_i - E_f$ – sharp lines

3

Photoelectric

$hf = \phi + KE_{max}$; a threshold frequency, not brightness

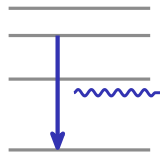
4

Nuclear

fission, fusion, decay; $E = mc^2$; half-life

Check yourself

- 1 What sets a single photon's energy?
- 2 Why does an atom emit only certain colours?
- 3 Below the threshold frequency, does brighter light eject electrons?
- 4 After two half-lives, what fraction of a sample remains?



Answers 1. its frequency ($E = hf$) 2. quantized energy levels 3. no 4. one quarter