Modern Physics

AP Physics 2 ▪ Unit 15

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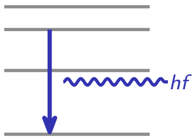
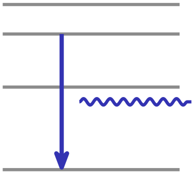


What we will cover



1 Photons & duality

Photons and wave-particle duality

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

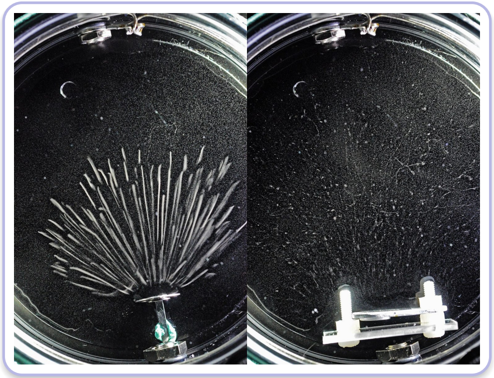
Photon energy

$$E = hf$$

Matter waves

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

the **de Broglie wavelength** 德布罗意波长.



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.

2 Bohr model

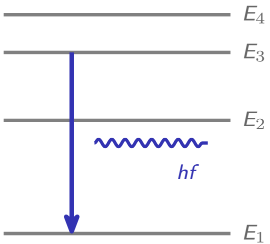
The Bohr model and energy levels

The **Bohr model** 玻尔模型: electrons occupy only certain **energy levels** 能级 – energy is quantized.

A jump emits or absorbs a photon

$$E = hf = E_i - E_f$$

Hydrogen $-3.4 \to -13.6\,\mathrm{eV}$: emits a $10.2\,\mathrm{eV}$ photon.



3 Spectra

Spectra and blackbody radiation

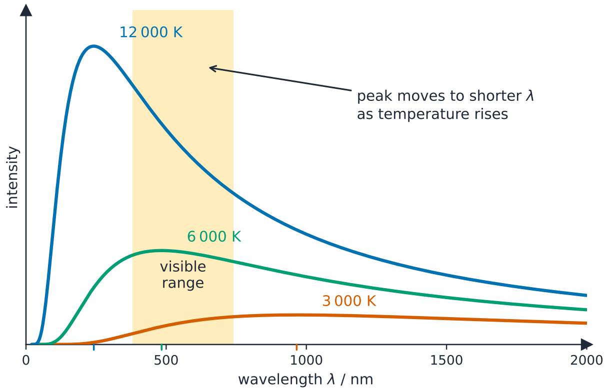
Discrete levels give sharp spectral lines – a fingerprint of each element:

- **emission** 发射光谱: bright lines (electrons drop)
- **absorption** 吸收光谱: dark lines in a rainbow (photons absorbed)

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

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

4 Photoelectric

The photoelectric effect

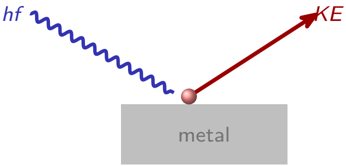
Light ejects electrons from a metal – only if each photon is energetic enough:

One photon, one electron

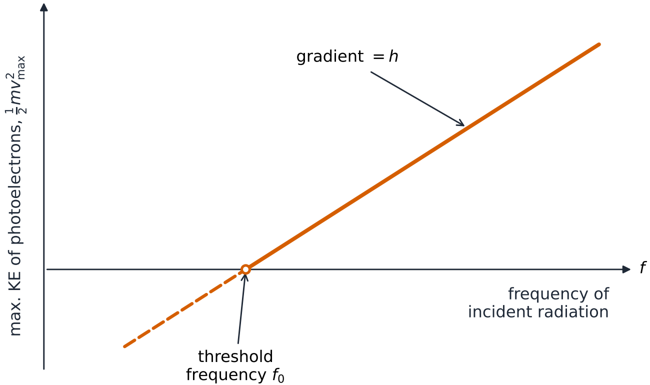
$$E = hf = \phi + KE_{max}$$

work function 逸出功 ϕ = energy to escape.

Below the **threshold frequency** 截止频率, 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

5

Compton

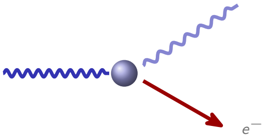
Compton scattering

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

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.



6 Nuclear

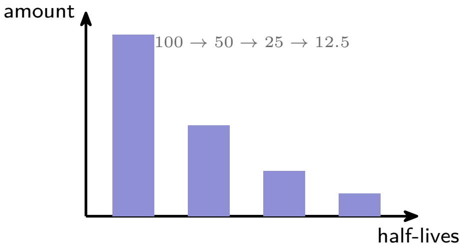
Nuclear physics

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

Mass-energy

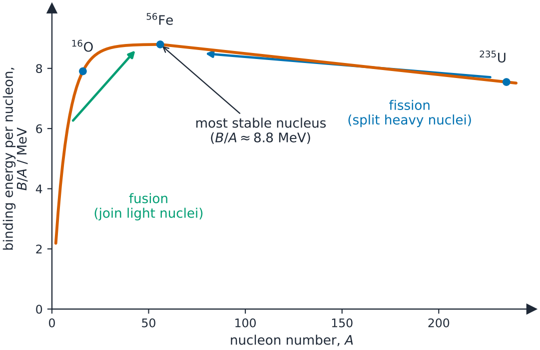
$$E = mc^2$$

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



Half-life 半衰期: time for half to decay.

Binding energy per nucleon peaks near iron

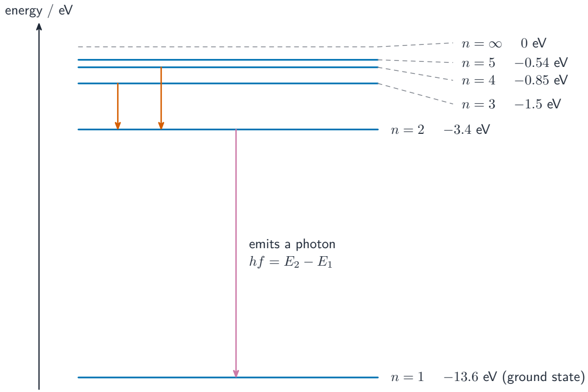


> Binding energy per nucleon peaks near iron, so both fusion and fission can release energy

Emission and Absorption Spectra

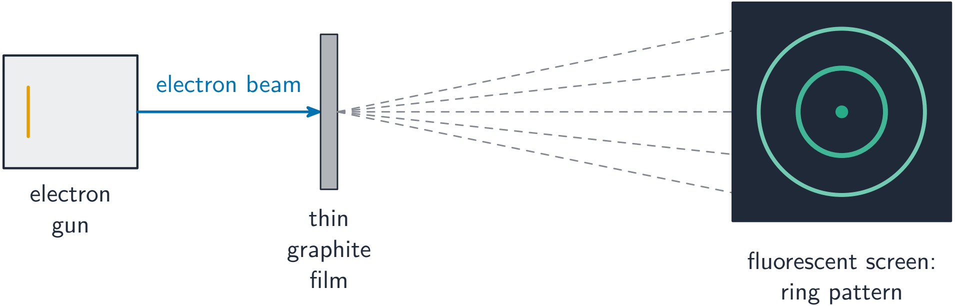
Hydrogen's emission spectrum: each bright line is light from an electron dropping between fixed energy levels

The discrete energy levels of hydrogen produce



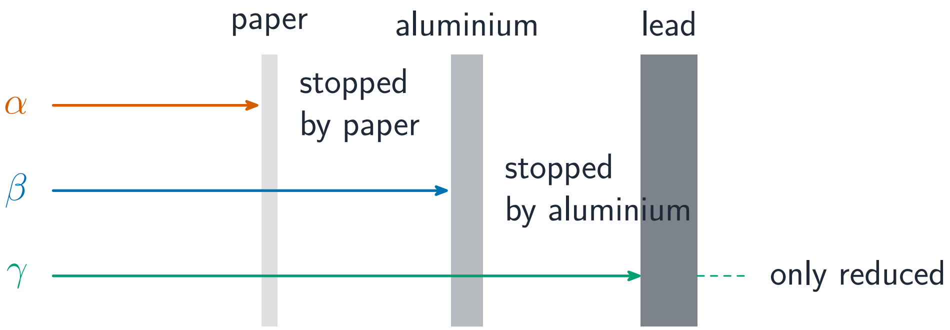
The discrete energy levels of hydrogen produce a line spectrum

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 量子	light arrives in discrete packets, which is why the photoelectric effect has a threshold frequency
the nucleus 原子核	stores enormous energy
fission 裂变	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 衰变 emits a helium nucleus; **beta decay** β 衰变 a fast electron or a **positron** 正电子. 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 $K_{\mathrm{max}} = hf - \phi$ 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).

7 Recap

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

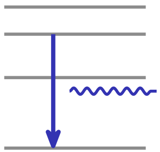
$hf = \phi + KE_{max}$; a threshold frequency, not brightness

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