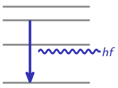
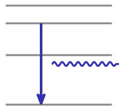
Modern Physics
AP Physics 2 ▪ Unit 15

AP Physics 2



What we will cover



1 Photons & duality

Photons and wave-particle duality

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

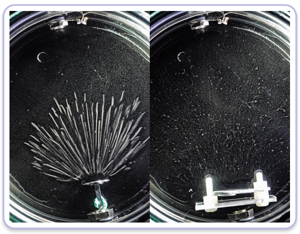
Photon energy

$$E = hf$$

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

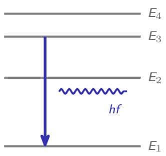
The Bohr model and energy levels

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

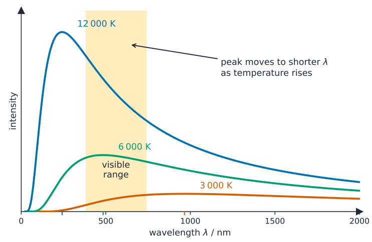
Discrete levels give sharp spectral lines – a fingerprint of each element:

- **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 ⇒ 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

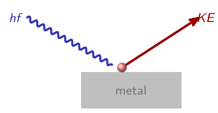
Light ejects electrons from a metal – only if each photon is energetic enough:

One photon, one electron

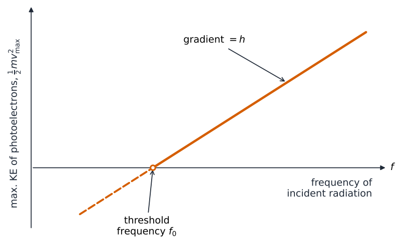
$$E = hf = \phi + KE_{max}$$

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

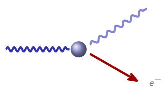
Compton scattering

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

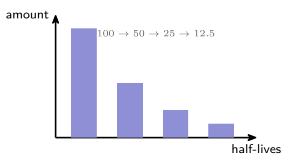
Nuclear physics

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

Mass-energy

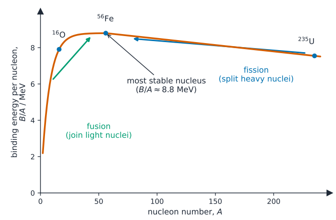
$$E = mc^2$$

- **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

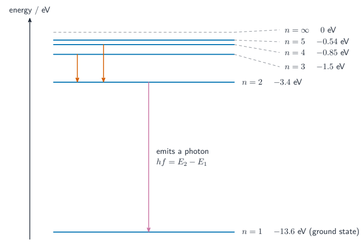


Binding energy per nucleon peaks near iron, so both fusion and fission can release energy

Emission and Absorption Spectra

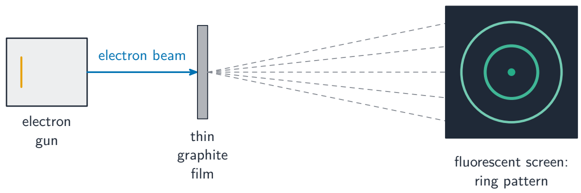
Hydrogen's emission spectrum: each bright line is light from an electron dropping between fixed energy levels

The discrete energy levels of hydrogen produce



The discrete energy levels of hydrogen produce a line spectrum

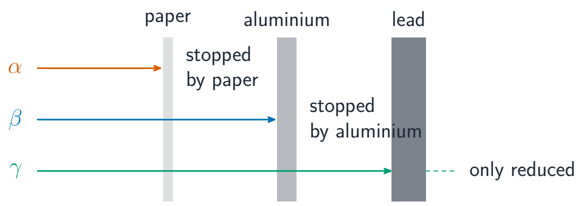
Quantum Theory and Wave-Particle Duality



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

Modern Physics
Nuclear

Types of Radioactive Decay



The penetrating power of alpha, beta, and gamma radiation

Modern Physics
Nuclear

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.

Modern Physics
Nuclear

Exam tips

- Photon energy is $E = hf$; below the **threshold frequency** no electrons are emitted **however bright** the light (the photoelectric effect).
- Use $K_{\max} = hf - \phi$ 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).

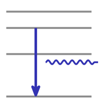
7 Recap

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