

Specification

Focus Questions

Every line of the AQA A-level Physics specification, rewritten as a question with the answer directly underneath. This free sample shows seven real pages from the full pack.

What's in this sample

- 3.2.1 Particles — the specification turned into questions, point by point
- 3.2.2 Quantum phenomena — the photoelectric effect and energy levels
- 3.6.1 Periodic motion — SHM worked step by step, with exam tips
- 3.7.4 Capacitance — exponential discharge and the log-linear method
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The full pack: 19 booklets, 192 pages

760 questions & answers · 135 worked examples · 232 exam tips

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3.2.1.1 Constituents of the atom

Q1. State the charge and mass of the proton, neutron and electron in SI and relative units.

Proton: $+1.60 \times 10^{-19}$ C, 1.67×10^{-27} kg; relative charge +1, relative mass 1. Neutron: 0 C, 1.67×10^{-27} kg; relative charge 0, relative mass 1. Electron: -1.60×10^{-19} C, 9.11×10^{-31} kg; relative charge -1, relative mass about 1/1840.

Q2. Define specific charge and state its unit.

The charge per unit mass of a particle, charge $\div$ mass, measured in C kg^{-1} .

Q3. Explain how the specific charge of a nucleus or ion is calculated. [Maths skill]

Find the total charge from the number of protons, minus electrons for a negative ion or plus for a positive ion, and the total mass from the number of nucleons. Then divide. The electron mass is usually negligible.

Q4. State which particle has the largest specific charge and why.

The electron. It has the same magnitude of charge as the proton but a mass about 1840 times smaller, giving a specific charge about 1840 times greater.

Q5. Explain the nuclide notation ${}^A_Z\text{X}$.

Z is the proton number, the number of protons, which identifies the element. A is the nucleon number, the total number of protons and neutrons. The number of neutrons is $A - Z$.

Q6. Define isotopes and explain why they behave identically in chemical reactions.

Atoms of the same element with the same proton number but different numbers of neutrons. Chemical behaviour depends on the electrons, and the number of electrons equals the proton number, so it is unchanged.

Q7. Give two uses of isotopic data.

Radioactive dating, such as carbon-14 dating of organic material and uranium dating of rocks, and medical tracers, where a short-lived isotope of an element is followed through the body.

WORKED EXAMPLE 1 • Specific charge of a nucleus [Maths skill]

Question: Find the specific charge of a ${}^{14}\text{N}$ nucleus ($Z = 7$). $e = 1.60 \times 10^{-19}$ C, nucleon mass 1.67×10^{-27} kg

Step 1: Charge = $7 \times 1.60 \times 10^{-19} = 1.12 \times 10^{-18}$ C

Step 2: Mass = $14 \times 1.67 \times 10^{-27} = 2.338 \times 10^{-26}$ kg

Step 3: Specific charge = $1.12 \times 10^{-18} \div 2.338 \times 10^{-26}$

Answer: $4.79 \times 10^7 \text{ C kg}^{-1}$

3.2.2.1 The photoelectric effect

Q1. Describe what happens in the photoelectric effect.

When electromagnetic radiation above a certain frequency falls on a metal surface, electrons are emitted from it immediately.

Q2. Define threshold frequency.

The minimum frequency of incident radiation that will cause photoelectric emission from a given metal surface. Below it no electrons are emitted, however intense the radiation.

Q3. Define the work function.

The minimum energy required for an electron to escape from the surface of the metal, usually given the symbol ϕ and quoted in joules or electronvolts.

Q4. Give the relationship between work function and threshold frequency.

$\phi = hf_0$. At the threshold the photon energy is exactly enough to free the electron, leaving it with no kinetic energy.

Q5. State the photoelectric equation and define each term.

$hf = \phi + E_{k(\max)}$, where hf is the energy of one photon, ϕ the work function and $E_{k(\max)}$ the maximum kinetic energy of the emitted photoelectrons.

Q6. Explain why the equation gives the *maximum* kinetic energy.

Only electrons at the very surface need exactly the work function to escape. Electrons from below the surface lose additional energy on the way out, so they emerge with less kinetic energy, giving a range of values up to the maximum.

Q7. Explain the photon explanation of the threshold frequency.

One photon interacts with one electron and transfers all of its energy, hf . If hf is less than the work function, no single photon can supply enough energy for the electron to escape, and increasing the intensity simply delivers more photons of the same insufficient energy.

Q8. Explain why emission is instantaneous rather than delayed.

The energy arrives in a single packet and is transferred to one electron in one interaction, so there is no time needed to accumulate energy gradually as the wave model would require.

Q9. Explain the effect of increasing the intensity above the threshold frequency.

More photons arrive per second, so more electrons are emitted per second and the photocurrent increases. The maximum kinetic energy is unchanged, because each electron still interacts with just one photon of the same energy.

Q10. Explain why the wave model of light cannot account for the observations.

A wave delivers energy continuously and spread over the whole surface, so any frequency should eventually free an electron given enough time, and a more intense beam should give more energetic electrons. Neither is observed.

Q13. State the displacement equation and the expression for velocity in terms of displacement.

$x = A \cos \omega t$, for an oscillator released from maximum displacement, and $v = \pm \omega \sqrt{A^2 - x^2}$.

Q14. State the maximum speed and maximum acceleration.

Maximum speed = ωA , occurring at the equilibrium position. Maximum acceleration = $\omega^2 A$, occurring at maximum displacement.

Q15. Describe how the velocity-time and acceleration-time graphs are derived from the displacement-time graph. [Maths skill]

The velocity at any instant is the gradient of the displacement-time graph, and the acceleration is the gradient of the velocity-time graph. This relationship is explicitly examinable.

Q16. Describe the phase relationships between x , v and a .

If x is a cosine curve, v is a negative sine curve and a is a negative cosine curve. Velocity leads displacement by a quarter of a cycle, and acceleration is exactly antiphase with displacement.

Q17. Describe the graph of acceleration against displacement and state what the gradient gives. [Maths skill]

A straight line through the origin with a negative gradient. The straight line through the origin shows $a \propto x$, and the negative gradient shows that a is directed opposite to x . The gradient is $-\omega^2$.

Q18. Explain why the period of SHM is independent of amplitude.

Increasing the amplitude increases both the distance travelled and the maximum restoring force, and so the maximum speed, in the same proportion. The two effects cancel, so the time for one oscillation is unchanged.

WORKED EXAMPLE 3 · SHM calculations [Maths skill]

Question: An oscillator has amplitude 3.0 cm and frequency 2.4 Hz. Find the maximum speed, the maximum acceleration, and the speed at a displacement of 1.5 cm.

Step 1: $\omega = 2\pi f = 2\pi \times 2.4 = 15.08 \text{ rad s}^{-1}$

Step 2: $v_{\max} = \omega A = 15.08 \times 0.030 = 0.452 \text{ m s}^{-1}$

Step 3: $a_{\max} = \omega^2 A = 227.4 \times 0.030 = 6.82 \text{ m s}^{-2}$

Step 4: $v = \omega \sqrt{A^2 - x^2} = 15.08 \sqrt{(0.030^2 - 0.015^2)} = 15.08 \times 0.02598$

Answer: 0.452 m s^{-1} , 6.82 m s^{-2} , and 0.392 m s^{-1} at half the amplitude

Q19. Define the time constant and state its significance. □□□

$\tau = RC$, in seconds. It is the time for the charge, potential difference or current to fall to $1/e$, about 37%, of its initial value during discharge, or to rise to 63% of its final value during charging.

Q20. Show that RC has units of time. [Maths skill] □□□

R in $\Omega = V A^{-1}$ and C in F = $C V^{-1}$, so RC has units $V A^{-1} \times C V^{-1} = C A^{-1} = C \div (C s^{-1}) = s$.

Q21. State the time to halve and its relationship to the time constant. □□□

$T_{1/2} = 0.69RC$. It is constant throughout the decay, since the decay is exponential.

Q22. State the quantitative equations for capacitor discharge. □□□

$Q = Q_0 e^{-t/RC}$, and the corresponding equations $V = V_0 e^{-t/RC}$ and $I = I_0 e^{-t/RC}$, since all three are proportional to one another.

Q23. State the equation for capacitor charge. □□□

$Q = Q_0(1 - e^{-t/RC})$, where Q_0 is the final charge. The current during charging still falls as $I = I_0 e^{-t/RC}$.

Q24. Explain why the discharge curve never truly reaches zero. □□□

The rate of decay is proportional to the charge remaining, so as the charge falls the rate falls too. The exponential approaches zero asymptotically without ever reaching it, though after about five time constants less than 1% remains.

Q25. Describe how log-linear plotting is used to find the time constant. □□□

[Maths skill]

Take natural logarithms of $V = V_0 e^{-t/RC}$ to give $\ln V = \ln V_0 - t/RC$. A plot of $\ln V$ against t is a straight line of gradient $-1/RC$, so the time constant is the negative reciprocal of the gradient, and the intercept gives $\ln V_0$.

Q26. Describe Required practical 9. [Maths skill] □□□

Investigate the charge and discharge of capacitors. Charge the capacitor through a two-way switch from a supply, then discharge it through a known resistor, recording the potential difference at regular intervals with a high-resistance voltmeter or datalogger. Plot V against t to show the exponential shape, and $\ln V$ against t to find RC from the gradient. A high-resistance voltmeter is essential so that it does not provide a second discharge path.

WORKED EXAMPLE 3 · Discharge calculation [Maths skill]

Question: A $470 \mu F$ capacitor charged to 12 V discharges through a $33 k\Omega$ resistor. Find the time constant, the time to halve, and the p.d. after 25 s.

Step 1: $\tau = RC = 33\,000 \times 470 \times 10^{-6} = 15.5 \text{ s}$

Step 2: $T_{1/2} = 0.69RC = 0.69 \times 15.5 = 10.7 \text{ s}$

Step 3: $V = V_0 e^{(-t/RC)} = 12 \times e^{(-25 \div 15.5)} = 12 \times e^{(-1.613)}$

Step 4: $= 12 \times 0.1993$

Answer: $\tau = 15.5 \text{ s}$, $T_{1/2} = 10.7 \text{ s}$, and $V = 2.39 \text{ V}$ after 25 s

Q8. Explain the relative hazards of the three radiations outside and inside the body. ☐☐☐

Outside the body alpha is least hazardous, since it cannot penetrate the dead outer layer of skin, while gamma is most hazardous because it reaches internal organs. Inside the body alpha is by far the most hazardous, because it deposits all its energy in a very short range within living tissue.

Q9. Explain how the thickness of a material is monitored using radiation. ☐☐☐

A source is placed on one side of the sheet and a detector on the other, and the count rate indicates the thickness. Beta is used for aluminium foil and paper, since its absorption is sensitive to small thickness changes, and gamma for steel, since beta would not penetrate it at all.

Q10. State the inverse square law for gamma radiation and explain it. ☐☐☐

$I = k/x^2$, where I is the intensity and x the distance from the source. The same power spreads over the surface of a sphere of area $4\pi x^2$, so the intensity falls as the square of the distance.

Q11. Describe Required practical 12. [Maths skill] ☐☐☐

Investigate the inverse square law for gamma radiation. Measure the background count rate with no source. Place a gamma source at a series of measured distances from a Geiger-Müller tube, recording the count over a fixed time at each. Subtract the background from each reading. Plot corrected count rate against $1/x^2$, which should give a straight line through the origin.

Q12. Explain how the inverse square law applies to the safe handling of sources. ☐☐☐

The intensity falls very rapidly with distance, so handling a source with long tongs rather than fingers reduces the dose enormously. Doubling the distance reduces the intensity to a quarter.

Q13. Name the main sources of background radiation and explain how it is eliminated from calculations. ☐☐☐

Radon gas from rocks and soil, cosmic rays, gamma rays from rocks and building materials, food and drink, and a small medical and industrial contribution. The background count rate is measured with no source present and subtracted from every reading.

Q14. Discuss the balance of risk and benefit in the medical use of radiation. ☐☐☐

Radiation can damage DNA and cause cancer, so every exposure carries a risk. Against this, diagnostic imaging and radiotherapy save lives, and the dose is minimised by choosing the shortest half-life and lowest activity adequate for the purpose, shielding, and limiting exposure time.

WORKED EXAMPLE 4 · Distance from magnitudes [Maths skill]

Question: A star has apparent magnitude 7.4 and absolute magnitude 2.1. Find its distance in parsecs.

Step 1: $m - M = 5 \log(d/10)$

Step 2: $7.4 - 2.1 = 5.3 = 5 \log(d/10)$

Step 3: $\log(d/10) = 1.06$, so $d/10 = 10^{1.06} = 11.48$

Answer: 115 parsecs

WORKED EXAMPLE 5 · Intensity ratio from magnitudes [Maths skill]

Question: Two stars differ by 3.5 magnitudes. Find the ratio of their intensities.

Step 1: Each magnitude is a factor of 2.51

Step 2: Ratio = $2.51^{3.5}$

Answer: 25.1 times — the brighter star is 25 times more intense

EXAM TIP

In $m - M = 5 \log(d/10)$, d is in **parsecs**. Convert light years or metres first.

EXAM TIP

Rearranging for d needs care: $d = 10 \times 10^{((m - M)/5)}$.

3.9.2.3 Classification by temperature

Q23. State Wien's displacement law and its use. [Maths skill]

$\lambda_{\max} T = 2.9 \times 10^{-3} \text{ m K}$. Measuring the wavelength of peak emission gives the black body temperature of the source. Experimental verification is not required by this specification.

Q24. State Stefan's law and define each term.

$P = \sigma AT^4$, where P is the total power output, A the surface area, T the absolute temperature and σ the Stefan constant. It is used to compare the power output, temperature and size of stars.

Q25. Describe the general shape of a black body curve and how it changes with temperature.

Intensity rises from zero at short wavelengths to a peak and falls away more gradually at long wavelengths. A hotter body emits more at every wavelength and its peak moves to shorter wavelengths.

WORKED EXAMPLE 5 · Indicated and brake power [Maths skill]

Question: A four-cylinder four-stroke engine runs at $3000 \text{ rev min}^{-1}$ with a p-V loop area of 420 J. The output torque is 85 N m. Find the indicated power, brake power and mechanical efficiency.

Step 1: Rotational frequency = $3000 \div 60 = 50 \text{ rev s}^{-1}$

Step 2: Four-stroke, so cycles per second = $50 \div 2 = 25$

Step 3: Indicated power = $420 \times 25 \times 4 = 42\,000 \text{ W}$

Step 4: $\omega = 2\pi \times 50 = 314 \text{ rad s}^{-1}$, so brake power = $T\omega = 85 \times 314 = 26\,700 \text{ W}$

Step 5: Mechanical efficiency = $26\,700 \div 42\,000$

Answer: Indicated 42.0 kW, brake 26.7 kW, mechanical efficiency 64%

WORKED EXAMPLE 6 · Overall efficiency [Maths skill]

Question: The engine above burns fuel of calorific value 45 MJ kg^{-1} at 3.5 g s^{-1} . Find the input power and the overall and thermal efficiencies.

Step 1: Input power = calorific value $\times$ fuel flow rate = $45 \times 10^6 \times 3.5 \times 10^{-3} = 157\,500 \text{ W}$

Step 2: Overall = brake $\div$ input = $26\,700 \div 157\,500 = 0.170$

Step 3: Thermal = indicated $\div$ input = $42\,000 \div 157\,500 = 0.267$

Step 4: Check: $0.267 \times 0.64 = 0.170 \checkmark$

Answer: Input 158 kW, overall efficiency 17%, thermal efficiency 27%

EXAM TIP

A four-stroke engine completes one cycle every **two** revolutions. Halve the rotational frequency to get cycles per second, or the indicated power doubles.

EXAM TIP

Overall = thermal $\times$ mechanical. Use that as a check on all three efficiency calculations.

EXAM TIP

Friction does **not** account for the difference in area between the theoretical and actual indicator diagrams. The report calls this a very common misunderstanding — the area difference comes from the real processes not being ideal.

3.11.2.5 The second law and engines

Q41. Explain why an engine cannot work by the first law alone.



The first law allows energy to be conserved while all the heat supplied is converted to work, but this is never observed. A further principle is needed to explain why some energy must always be rejected.

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