3 Subject content

All candidates should be taught the Core subject content. Candidates who are only taught the Core subject content can achieve a maximum of grade C. Candidates aiming for grades A* to C should be taught the Extended subject content. The Extended subject content includes both the Core and the Supplement.

Scientific subjects are, by their nature, experimental. Learners should pursue a fully integrated course which allows them to develop their practical skills by carrying out practical work and investigations within all of the topics listed.

1 General physics

1.1 Length and time

Core

- Use and describe the use of rules and measuring cylinders to find a length or a volume
- Use and describe the use of clocks and devices, both analogue and digital, for measuring an interval of time
- Obtain an average value for a small distance and for a short interval of time by measuring multiples (including the period of a pendulum)

Supplement

- Understand that a micrometer screw gauge is used to measure very small distances

1.2 Motion

Core

- Define speed and calculate average speed from $\frac{\text{total distance}}{\text{total time}}$
- Plot and interpret a speed-time graph or a distance-time graph
- Recognise from the shape of a speed-time graph when a body is
  - at rest
  - moving with constant speed
  - moving with changing speed
- Calculate the area under a speed-time graph to work out the distance travelled for motion with constant acceleration
- Demonstrate understanding that acceleration and deceleration are related to changing speed including qualitative analysis of the gradient of a speed-time graph
- State that the acceleration of free fall for a body near to the Earth is constant

Supplement

- Distinguish between speed and velocity
- Define and calculate acceleration using $\frac{\text{change of velocity}}{\text{time taken}}$
- Calculate speed from the gradient of a distance-time graph
- Calculate acceleration from the gradient of a speed-time graph
- Recognise linear motion for which the acceleration is constant
- Recognise motion for which the acceleration is not constant
- Understand deceleration as a negative acceleration
- Describe qualitatively the motion of bodies falling in a uniform gravitational field with and without air resistance (including reference to terminal velocity)

1.3 Mass and weight

Core

- Show familiarity with the idea of the mass of a body
- State that weight is a gravitational force
- Distinguish between mass and weight
- Recall and use the equation $W = mg$
- Demonstrate understanding that weights (and hence masses) may be compared using a balance

Supplement

- Demonstrate an understanding that mass is a property that 'resists' change in motion
- Describe, and use the concept of, weight as the effect of a gravitational field on a mass

1.4 Density

Core

- Recall and use the equation $\rho = \frac{m}{V}$
- Describe an experiment to determine the density of a liquid and of a regularly shaped solid and make the necessary calculation
- Describe the determination of the density of an irregularly shaped solid by the method of displacement
- Predict whether an object will float based on density data

1.5 Forces

1.5.1 Effects of forces

Core

- Recognise that a force may produce a change in size and shape of a body
- Plot and interpret extension-load graphs and describe the associated experimental procedure
- Describe the ways in which a force may change the motion of a body
- Find the resultant of two or more forces acting along the same line
- Recognise that if there is no resultant force on a body it either remains at rest or continues at constant speed in a straight line
- Understand friction as the force between two surfaces which impedes motion and results in heating
- Recognise air resistance as a form of friction

Supplement

- State Hooke's Law and recall and use the expression $F = kx$, where k is the spring constant
- Recognise the significance of the 'limit of proportionality' for an extension-load graph
- Recall and use the relationship between force, mass and acceleration (including the direction), $F = ma$
- Describe qualitatively motion in a circular path due to a perpendicular force ($F = mv^2/r$ is not required)

1.5.2 Turning effect

Core

- Describe the moment of a force as a measure of its turning effect and give everyday examples
- Understand that increasing force or distance from the pivot increases the moment of a force
- Calculate moment using the product force × perpendicular distance from the pivot
- Apply the principle of moments to the balancing of a beam about a pivot

Supplement

- Apply the principle of moments to different situations

1.5.3 Conditions for equilibrium

Core

- Recognise that, when there is no resultant force and no resultant turning effect, a system is in equilibrium

Supplement

- Perform and describe an experiment (involving vertical forces) to show that there is no net moment on a body in equilibrium

1.5.4 Centre of mass

Core

- Perform and describe an experiment to determine the position of the centre of mass of a plane lamina
- Describe qualitatively the effect of the position of the centre of mass on the stability of simple objects

1.5.5 Scalars and vectors

Supplement

- Understand that vectors have a magnitude and direction
- Demonstrate an understanding of the difference between scalars and vectors and give common examples
- Determine graphically the resultant of two vectors

1.6 Momentum

Supplement

- Understand the concepts of momentum and impulse
- Recall and use the equation momentum = mass × velocity, $p = mv$
- Recall and use the equation for impulse $Ft = mv - mu$
- Apply the principle of the conservation of momentum to solve simple problems in one dimension

1.7 Energy, work and power

1.7.1 Energy

Core

- Identify changes in kinetic, gravitational potential, chemical, elastic (strain), nuclear and internal energy that have occurred as a result of an event or process
- Recognise that energy is transferred during events and processes, including examples of transfer by forces (mechanical working), by electrical currents (electrical working), by heating and by waves
- Apply the principle of conservation of energy to simple examples

Supplement

- Recall and use the expressions kinetic energy = $\frac{1}{2}mv^2$ and change in gravitational potential energy = $mg\Delta h$
- Apply the principle of conservation of energy to examples involving multiple stages
- Explain that in any event or process the energy tends to become more spread out among the objects and surroundings (dissipated)

1.7.2 Energy resources

Core

- Describe how electricity or other useful forms of energy may be obtained from:
  - chemical energy stored in fuel
  - water, including the energy stored in waves, in tides, and in water behind hydroelectric dams
  - geothermal resources
  - nuclear fission
  - heat and light from the Sun (solar cells and panels)
  - wind
- Give advantages and disadvantages of each method in terms of renewability, cost, reliability, scale and environmental impact
- Show a qualitative understanding of efficiency

Supplement

- Understand that the Sun is the source of energy for all our energy resources except geothermal, nuclear and tidal
- Show an understanding that energy is released by nuclear fusion in the Sun
- Recall and use the equations:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{power input}} \times 100\%$$

1.7.3 Work

Core

- Demonstrate understanding that work done = energy transferred
- Relate (without calculation) work done to the magnitude of a force and the distance moved in the direction of the force

Supplement

- Recall and use $W = Fd = \Delta E$

1.7.4 Power

Core

- Relate (without calculation) power to work done and time taken, using appropriate examples

Supplement

- Recall and use the equation $P = \Delta E / t$ in simple systems

1.8 Pressure

Core

- Recall and use the equation $p = F/A$
- Relate pressure to force and area, using appropriate examples
- Describe the simple mercury barometer and its use in measuring atmospheric pressure
- Relate (without calculation) the pressure beneath a liquid surface to depth and to density, using appropriate examples
- Use and describe the use of a manometer

Supplement

- Recall and use the equation $p = h\rho g$

2 Thermal physics

2.1 Simple kinetic molecular model of matter

2.1.1 States of matter

Core

- State the distinguishing properties of solids, liquids and gases

2.1.2 Molecular model

Core

- Describe qualitatively the molecular structure of solids, liquids and gases in terms of the arrangement, separation and motion of the molecules
- Interpret the temperature of a gas in terms of the motion of its molecules
- Describe qualitatively the pressure of a gas in terms of the motion of its molecules
- Show an understanding of the random motion of particles in a suspension as evidence for the kinetic molecular model of matter
- Describe this motion (sometimes known as Brownian motion) in terms of random molecular bombardment

Supplement

- Relate the properties of solids, liquids and gases to the forces and distances between molecules and to the motion of the molecules
- Explain pressure in terms of the change of momentum of the particles striking the walls creating a force
- Show an appreciation that massive particles may be moved by light, fast-moving molecules

2.1.3 Evaporation

Core

- Describe evaporation in terms of the escape of more-energetic molecules from the surface of a liquid
- Relate evaporation to the consequent cooling of the liquid

Supplement

- Demonstrate an understanding of how temperature, surface area and draught over a surface influence evaporation
- Explain the cooling of a body in contact with an evaporating liquid

2.1.4 Pressure changes

Core

- Describe qualitatively, in terms of molecules, the effect on the pressure of a gas of:
  - a change of temperature at constant volume
  - a change of volume at constant temperature

Supplement

- Recall and use the equation pV = constant for a fixed mass of gas at constant temperature

2.2 Thermal properties and temperature

2.2.1 Thermal expansion of solids, liquids and gases

Core

- Describe qualitatively the thermal expansion of solids, liquids, and gases at constant pressure
- Identify and explain some of the everyday applications and consequences of thermal expansion

Supplement

- Explain, in terms of the motion and arrangement of molecules, the relative order of the magnitude of the expansion of solids, liquids and gases

2.2.2 Measurement of temperature

Core

- Appreciate how a physical property that varies with temperature may be used for the measurement of temperature, and state examples of such properties
- Recognise the need for and identify fixed points
- Describe and explain the structure and action of liquid-in-glass thermometers

Supplement

- Demonstrate understanding of sensitivity, range and linearity
- Describe the structure of a thermocouple and show understanding of its use as a thermometer for measuring high temperatures and those that vary rapidly
- Describe and explain how the structure of a liquid-in-glass thermometer relates to its sensitivity, range and linearity

2.2.3 Thermal capacity (heat capacity)

Core

- Relate a rise in the temperature of a body to an increase in its internal energy
- Show an understanding of what is meant by the thermal capacity of a body

Supplement

- Give a simple molecular account of an increase in internal energy
- Recall and use the equation thermal capacity = mc
- Define specific heat capacity
- Describe an experiment to measure the specific heat capacity of a substance
- Recall and use the equation change in energy = $mc\Delta T$

2.2.4 Melting and boiling

Core

- Describe melting and boiling in terms of energy input without a change in temperature
- State the meaning of melting point and boiling point
- Describe condensation and solidification in terms of molecules

Supplement

- Distinguish between boiling and evaporation
- Use the terms latent heat of vaporisation and latent heat of fusion and give a molecular interpretation of latent heat
- Define specific latent heat
- Describe an experiment to measure specific latent heats for steam and for ice
- Recall and use the equation energy = ml

2.3 Thermal processes

2.3.1 Conduction

Core

- Describe experiments to demonstrate the properties of good and bad thermal conductors

Supplement

- Give a simple molecular account of conduction in solids including lattice vibration and transfer by electrons

2.3.2 Convection

Core

- Recognise convection as an important method of thermal transfer in fluids
- Relate convection in fluids to density changes and describe experiments to illustrate convection

2.3.3 Radiation

Core

- Identify infra-red radiation as part of the electromagnetic spectrum
- Recognise that thermal energy transfer by radiation does not require a medium
- Describe the effect of surface colour (black or white) and texture (dull or shiny) on the emission, absorption and reflection of radiation

Supplement

- Describe experiments to show the properties of good and bad emitters and good and bad absorbers of infra-red radiation
- Show understanding that the amount of radiation emitted also depends on the surface temperature and surface area of a body

2.3.4 Consequences of energy transfer

Core

- Identify and explain some of the everyday applications and consequences of conduction, convection and radiation

3 Properties of waves, including light and sound

3.1 General wave properties

Core

- Demonstrate understanding that waves transfer energy without transferring matter
- Describe what is meant by wave motion as illustrated by vibration in ropes and springs and by experiments using water waves
- Use the term wavefront
- Give the meaning of speed, frequency, wavelength and amplitude
- Distinguish between transverse and longitudinal waves and give suitable examples
- Describe how waves can undergo:
  - reflection at a plane surface
  - refraction due to a change of speed
  - diffraction through a narrow gap
- Describe the use of water waves to demonstrate reflection, refraction and diffraction

Supplement

- Recall and use the equation $v = f\lambda$
- Describe how wavelength and gap size affects diffraction through a gap
- Describe how wavelength affects diffraction at an edge

3.2 Light

3.2.1 Reflection of light

Core

- Describe the formation of an optical image by a plane mirror, and give its characteristics
- Recall and use the law angle of incidence = angle of reflection

Supplement

- Recall that the image in a plane mirror is virtual
- Perform simple constructions, measurements and calculations for reflection by plane mirrors

3.2.2 Refraction of light

Core

- Describe an experimental demonstration of the refraction of light
- Use the terminology for the angle of incidence *i* and angle of refraction *r* and describe the passage of light through parallel-sided transparent material
- Give the meaning of critical angle
- Describe internal and total internal reflection

Supplement

- Recall and use the definition of refractive index *n* in terms of speed
- Recall and use the equation $\frac{\sin i}{\sin r} = n$
- Recall and use $n = \frac{1}{\sin c}$
- Describe and explain the action of optical fibres particularly, in medicine and communications technology

3.2.3 Thin converging lens

Core

- Describe the action of a thin converging lens on a beam of light
- Use the terms principal focus and focal length
- Draw ray diagrams for the formation of a real image by a single lens
- Describe the nature of an image using the terms enlarged/same size/diminished and upright/inverted

Supplement

- Draw and use ray diagrams for the formation of a virtual image by a single lens
- Use and describe the use of a single lens as a magnifying glass
- Show understanding of the terms real image and virtual image

3.2.4 Dispersion of light

Core

- Give a qualitative account of the dispersion of light as shown by the action on light of a glass prism including the seven colours of the spectrum in their correct order

Supplement

- Recall that light of a single frequency is described as monochromatic

3.3 Electromagnetic spectrum

Core

- Describe the main features of the electromagnetic spectrum in order of wavelength
- State that all electromagnetic waves travel with the same high speed in a vacuum
- Describe typical properties and uses of radiations in all the different regions of the electromagnetic spectrum including:
  - radio and television communications (radio waves)
  - satellite television and telephones (microwaves)
  - electrical appliances, remote controllers for televisions and intruder alarms (infra-red)
  - medicine and security (X-rays)
- Demonstrate an awareness of safety issues regarding the use of microwaves and X-rays

Supplement

- State that the speed of electromagnetic waves in a vacuum is 3.0×10^8 m/s and is approximately the same in air

3.4 Sound

Core

- Describe the production of sound by vibrating sources
- Describe the longitudinal nature of sound waves
- State that the approximate range of audible frequencies for a healthy human ear is 20 Hz to 20 000 Hz
- Show an understanding of the term ultrasound
- Show an understanding that a medium is needed to transmit sound waves
- Describe an experiment to determine the speed of sound in air
- Relate the loudness and pitch of sound waves to amplitude and frequency
- Describe how the reflection of sound may produce an echo

Supplement

- Describe compression and rarefaction
- State typical values of the speed of sound in gases, liquids and solids

4 Electricity and magnetism

4.1 Simple phenomena of magnetism

Core

- Describe the forces between magnets, and between magnets and magnetic materials
- Give an account of induced magnetism
- Distinguish between magnetic and non-magnetic materials
- Describe methods of magnetisation, to include stroking with a magnet, use of direct current (d.c.) in a coil and hammering in a magnetic field
- Draw the pattern of magnetic field lines around a bar magnet
- Describe an experiment to identify the pattern of magnetic field lines, including the direction
- Distinguish between the magnetic properties of soft iron and steel
- Distinguish between the design and use of permanent magnets and electromagnets

Supplement

- Explain that magnetic forces are due to interactions between magnetic fields
- Describe methods of demagnetisation, to include hammering, heating and use of alternating current (a.c.) in a coil

4.2 Electrical quantities

4.2.1 Electric charge

Core

- State that there are positive and negative charges
- State that unlike charges attract and that like charges repel
- Describe simple experiments to show the production and detection of electrostatic charges
- State that charging a body involves the addition or removal of electrons
- Distinguish between electrical conductors and insulators and give typical examples

Supplement

- State that charge is measured in coulombs
- State that the direction of an electric field at a point is the direction of the force on a positive charge at that point
- Describe an electric field as a region in which an electric charge experiences a force
- Describe simple field patterns, including the field around a point charge, the field around a charged conducting sphere and the field between two parallel plates (not including end effects)
- Give an account of charging by induction
- Recall and use a simple electron model to distinguish between conductors and insulators

4.2.2 Current

Core

- State that current is related to the flow of charge
- Use and describe the use of an ammeter, both analogue and digital
- State that current in metals is due to a flow of electrons

Supplement

- Show understanding that a current is a rate of flow of charge and recall and use the equation $I = Q/t$
- Distinguish between the direction of flow of electrons and conventional current

4.2.3 Electromotive force

Core

- State that the electromotive force (e.m.f.) of an electrical source of energy is measured in volts

Supplement

- Show understanding that e.m.f. is defined in terms of energy supplied by a source in driving charge round a complete circuit

4.2.4 Potential difference

Core

- State that the potential difference (p.d.) across a circuit component is measured in volts
- Use and describe the use of a voltmeter, both analogue and digital

Supplement

- Recall that 1 V is equivalent to 1 J/C

4.2.5 Resistance

Core

- State that resistance = p.d./current and understand qualitatively how changes in p.d. or resistance affect current
- Recall and use the equation $R = V/I$
- Describe an experiment to determine resistance using a voltmeter and an ammeter
- Relate (without calculation) the resistance of a wire to its length and to its diameter

Supplement

- Sketch and explain the current-voltage characteristic of an ohmic resistor and a filament lamp
- Recall and use quantitatively the proportionality between resistance and length, and the inverse proportionality between resistance and cross-sectional area of a wire

4.2.6 Electrical working

Core

- Understand that electric circuits transfer energy from the battery or power source to the circuit components then into the surroundings

Supplement

- Recall and use the equations $P = IV$ and $E = IVt$

4.3 Electric circuits

4.3.1 Circuit diagrams

Core

- Draw and interpret circuit diagrams containing sources, switches, resistors (fixed and variable), heaters, thermistors, light-dependent resistors, lamps, ammeters, voltmeters, galvanometers, magnetising coils, transformers, bells, fuses and relays

Supplement

- Draw and interpret circuit diagrams containing diodes

4.3.2 Series and parallel circuits

Core

- Understand that the current at every point in a series circuit is the same
- Give the combined resistance of two or more resistors in series
- State that, for a parallel circuit, the current from the source is larger than the current in each branch
- State that the combined resistance of two resistors in parallel is less than that of either resistor by itself
- State the advantages of connecting lamps in parallel in a lighting circuit

Supplement

- Calculate the combined e.m.f. of several sources in series
- Recall and use the fact that the sum of the p.d.s across the components in a series circuit is equal to the total p.d. across the supply
- Recall and use the fact that the current from the source is the sum of the currents in the separate branches of a parallel circuit
- Calculate the effective resistance of two resistors in parallel

4.3.3 Action and use of circuit components

Core

- Describe the action of a variable potential divider (potentiometer)
- Describe the action of thermistors and light-dependent resistors and show understanding of their use as input transducers
- Describe the action of a relay and show understanding of its use in switching circuits

Supplement

- Describe the action of a diode and show understanding of its use as a rectifier
- Recognise and show understanding of circuits operating as light-sensitive switches and temperature-operated alarms (to include the use of a relay)

4.4 Digital electronics

Supplement

- Explain and use the terms analogue and digital in terms of continuous variation and high/low states
- Describe the action of NOT, AND, OR, NAND and NOR gates
- Recall and use the symbols for logic gates
- Design and understand simple digital circuits combining several logic gates
- Use truth tables to describe the action of individual gates and simple combinations of gates

4.5 Dangers of electricity

Core

- State the hazards of:
  - damaged insulation
  - overheating of cables
  - damp conditions
- State that a fuse protects a circuit
- Explain the use of fuses and circuit breakers and choose appropriate fuse ratings and circuit-breaker settings
- Explain the benefits of earthing metal cases

4.6 Electromagnetic effects

4.6.1 Electromagnetic induction

Core

- Show understanding that a conductor moving across a magnetic field or a changing magnetic field linking with a conductor can induce an e.m.f. in the conductor
- Describe an experiment to demonstrate electromagnetic induction
- State the factors affecting the magnitude of an induced e.m.f.

Supplement

- Show understanding that the direction of an induced e.m.f. opposes the change causing it
- State and use the relative directions of force, field and induced current

4.6.2 a.c. generator

Core

- Distinguish between d.c. and a.c.

Supplement

- Describe and explain a rotating-coil generator and the use of slip rings
- Sketch a graph of voltage output against time for a simple a.c. generator
- Relate the position of the generator coil to the peaks and zeros of the voltage output

4.6.3 Transformer

Core

- Describe the construction of a basic transformer with a soft-iron core, as used for voltage transformations
- Recall and use the equation $(V_p / V_s) = (N_p / N_s)$
- Understand the terms step-up and step-down
- Describe the use of the transformer in high-voltage transmission of electricity
- Give the advantages of high-voltage transmission

Supplement

- Describe the principle of operation of a transformer
- Recall and use the equation $I_p V_p = I_s V_s$ (for 100% efficiency)
- Explain why power losses in cables are lower when the voltage is high

4.6.4 The magnetic effect of a current

Core

- Describe the pattern of the magnetic field (including direction) due to currents in straight wires and in solenoids
- Describe applications of the magnetic effect of current, including the action of a relay

Supplement

- State the qualitative variation of the strength of the magnetic field over salient parts of the pattern
- State that the direction of a magnetic field line at a point is the direction of the force on the N pole of a magnet at that point
- Describe the effect on the magnetic field of changing the magnitude and direction of the current

4.6.5 Force on a current-carrying conductor

Core

- Describe an experiment to show that a force acts on a current-carrying conductor in a magnetic field, including the effect of reversing:
  - the current
  - the direction of the field

Supplement

- State and use the relative directions of force, field and current
- Describe an experiment to show the corresponding force on beams of charged particles

4.6.6 d.c. motor

Core

- State that a current-carrying coil in a magnetic field experiences a turning effect and that the effect is increased by:
  - increasing the number of turns on the coil
  - increasing the current
  - increasing the strength of the magnetic field

Supplement

- Relate this turning effect to the action of an electric motor including the action of a split-ring commutator

5 Atomic physics

5.1 The nuclear atom

5.1.1 Atomic model

Core

- Describe the structure of an atom in terms of a positive nucleus and negative electrons

Supplement

- Describe how the scattering of α-particles by thin metal foils provides evidence for the nuclear atom

5.1.2 Nucleus

Core

- Describe the composition of the nucleus in terms of protons and neutrons
- State the charges of protons and neutrons
- Use the term proton number Z
- Use the term nucleon number A
- Use the term nuclide and use the nuclide notation ${}^{A}_{Z}X$
- Use and explain the term isotope

Supplement

- State the meaning of nuclear fission and nuclear fusion
- Balance equations involving nuclide notation

5.2 Radioactivity

5.2.1 Detection of radioactivity

Core

- Demonstrate understanding of background radiation
- Describe the detection of α-particles, β-particles and γ-rays (β^+ are not included: β-particles will be taken to refer to β^-)

5.2.2 Characteristics of the three kinds of emission

Core

- Discuss the random nature of radioactive emission
- Identify α, β and γ-emissions by recalling
  - their nature
  - their relative ionising effects
  - their relative penetrating abilities (β^+ are not included, β-particles will be taken to refer to β^-)

Supplement

- Describe their deflection in electric fields and in magnetic fields
- Interpret their relative ionising effects
- Give and explain examples of practical applications of α, β and γ-emissions

5.2.3 Radioactive decay

Core

- State the meaning of radioactive decay
- State that during α- or β-decay the nucleus changes to that of a different element

Supplement

- Use equations involving nuclide notation to represent changes in the composition of the nucleus when particles are emitted

5.2.4 Half-life

Core

- Use the term half-life in simple calculations, which might involve information in tables or decay curves

Supplement

- Calculate half-life from data or decay curves from which background radiation has not been subtracted

5.2.5 Safety precautions

Core

- Recall the effects of ionising radiations on living things
- Describe how radioactive materials are handled, used and stored in a safe way