

**AM SYLLABUS (2020)**

**PHYSICS AM 26**

***SYLLABUS***

<b>Physics AM 26</b> (Available in September) <b>Syllabus</b> Paper 1 (3hrs) + Paper 2 (3hrs) + Practical paper 3 (2 hrs)
--

### Aims of the Advanced Level Physics Curriculum

A course of study intended to prepare students for the Advanced Level Matriculation Examination in Physics should:

- promote an understanding of the nature and essence of physical principles;
- foster implementation of the scientific approach in the analysis of real life situations;
- encourage the development of problem solving techniques;
- encourage the development of practical skills;
- provide an appreciation that physical laws are universal;
- foster an appreciation and enjoyment of physics as a part of universal human culture;
- cultivate an appreciation of the influence of physics in everyday life;
- encourage an understanding of technological applications of physics and its importance as a subject of social, economic and industrial relevance;
- encourage effective scientific communication and presentation.

### Assessment Objectives

- Knowledge with understanding (35%)
- Applications of concepts and principles (30%)
- Communication and presentation (10%)
- Experimental design, investigation and analysis (25%)

### Grade Descriptions

The grade descriptions indicate the criteria for awarding grades A, C and E. These criteria indicate the extent to which the assessment objectives are attained.

Objective/s	A	C	E
The candidate recalls and uses <b>knowledge</b> of Physics from...	the whole syllabus	most of the syllabus	some parts of the syllabus
The demonstration of the <b>understanding</b> of the principles and concepts is...	excellent	fair	Poor
The candidate <b>applies appropriately physical concepts and principles</b> in situations...	which are both familiar and unfamiliar	which are familiar or unfamiliar but some guidance is provided	which are familiar or closely related to them
The candidate's level of <b>communication and presentation</b> is...	clear, concise and direct	satisfactory	decent
In experimental work, the candidate <b>makes and records measurements</b> which are...	sufficient	almost sufficient	incomplete
In experimental work, the candidate shows <b>awareness for precision</b> which is	full	fair	lacking
In experimental work, the candidate's <b>analysis of experimental data</b> is...	rigorous	adequate	mediocre

## Examination

THREE papers as follows:

Paper I: 3 hours.

Paper intended to assess candidates on the following topics: Physical Quantities (Section 1), Mechanics (Section 2), Materials (Section 4), Electric Currents (Section 5), Atomic, Nuclear and Particle Physics (Section 8).

Section A - 8 short questions (90 minutes). Allotted 10 marks each for a total of 80 marks out of a grand total of 400 marks for the entire examination.

Section B - 7 longer structured questions to choose 4 (90 minutes). Allotted 20 marks each for a total of 80 marks out of a grand total of 400 marks for the entire examination.

Marks: 40%.

Paper II: 3 hours.

Paper intended to assess candidates on the following topics: Thermal Physics (Section 3), Fields (Section 6), Vibrations and Waves (Section 7).

Section A - 8 short questions (90 minutes). Allotted 10 marks each for a total of 80 marks out of a grand total of 400 marks for the entire examination.

Section B - 7 longer structured questions to choose 4 (90 minutes). Allotted 20 marks each for a total of 80 marks out of a grand total of 400 marks for the entire examination.

Marks:

40%. Paper III: 2 hours.

Practical session: Experimental Physics (Section 9)

One experiment designed to take up to around 1 hour allotted for taking measurements. Questions will be set requiring candidates to present and analyse the experimental data and obtain from them specified quantities. Allotted 80 marks in total out of a grand total of 400 marks for the entire examination.

Marks: 20%.

Notes:

- (i) Each paper does not exclude requirement of knowledge of topics examined in any other paper.
- (ii) Scientific calculators may be used throughout the examination. Nevertheless, the use of graphical and/or programmable calculators is prohibited. Disciplinary action will be taken against students making use of such calculators.
- (iii) A Data and Formulae Booklet published by the MATSEC Board will be made available during the examination.

## Mathematical Requirements

Sufficient mathematical background is necessary for one to be able to understand and apply the principles of physics at this level. Below is a list of abilities the candidate should be able demonstrate. These should be considered an integral part of the subject and can be examined directly or indirectly.

### Topic

### Abilities and comments

#### (A) Arithmetic and computation

Candidates should be able to:

- (a) Express numbers using decimal and standard form.
- (b) Use electronic calculators to carry out calculations involving
  - (i) addition, subtraction, multiplication and division;
  - (ii) angles in both degrees and radians;
  - (iii) reciprocals, squares,  $\sin(\theta)$ ,  $\cos(\theta)$ ,  $\tan(\theta)$ ,  $x^n$ ,  $10^x$ ,  $e^x$  and their inverses, i.e. square roots,  $\sin^{-1}(\theta)$ ,  $\cos^{-1}(\theta)$ ,  $\tan^{-1}(\theta)$ ,  $\log(x)$  and  $\ln(x)$ ;
  - (iv) arithmetic means.
- (c) Manipulate numerical data appropriately.
- (d) State numerical answers to an appropriate number of significant figures.
- (e) Make approximate estimated to find the order of magnitude of numerical expressions.
- (f) Convert between seconds, minutes, hours, days and years. One year should be taken to be 365.25 days.

#### (B) Algebra

Candidates should be able to:

- (a) Manipulate algebraic expressions. For example, changing the subject of a formula; this can include terms having positive or negative, integer or fractional powers.
- (b) Solve algebraic equations including those involving inverse relationships and inverse square relationships.
- (c) Solve simultaneous equations and quadratic equations.
- (d) Construct and use simple mathematical equations to model a physical situation.
- (e) Identify situations where the use of a given mathematical model is inadequate.
- (f) Use of logarithms to manipulate expressions such as  $ab$ ,  $\frac{a}{b}$ ,  $x^n$ , and  $e^{kx}$ . Only logarithms to base 10 and natural logarithms will be examined.
- (g) Identify the meaning of and use the following symbols: =, >, <, >>, <<,  $\approx$ ,  $\propto$ ,  $\Sigma x$ ,  $\Delta x$  and  $\delta x$ .

#### (C) Geometry and trigonometry

Candidates should be able to:

- (a) State and use the equations for:
  - (i) the area and perimeter of triangles, rectangles, circles and composite shapes;
  - (ii) the surface areas and volumes of rectangular blocks, cylinders and spheres.
- (b) State and use Pythagoras' theorem.
- (c) Identify and use adjacent angles, vertically opposite angles, corresponding angles, alternate angles (or Z angles).

**Topic****Abilities and comments**

- (d) Identify similar triangles and use the ratio of their sides.
- (e) State and use the sum of the angles on a straight line.
- (f) State and use the sum of the internal angles of a triangle and a quadrilateral.
- (g) Define and use the sine, cosine and tangent functions.
- (h) State and use the relation  $\tan(\theta) = \frac{\sin(\theta)}{\cos(\theta)}$ .
- (i) State and use the equations  $\sin(90^\circ - \theta) = \cos(\theta)$  and  $\sin(\theta + 90^\circ) = \cos(\theta)$ .
- (j) Relate angles measured in degrees to those measured in radians, and transform from one to the other ensuring that the appropriate system is used.
- (k) State and use the small angle approximations  $\sin(\theta) \approx \tan(\theta) \approx \theta$  and  $\cos(\theta) \approx 1$ , making sure  $\theta$  is measured in radians.

**Syllabus****Content****Learning outcomes and comments**

## 1. Physical quantities

## 1.1 Quantities and units of the S.I. system

Candidates should be able to:

- Explain what physical quantities and units are.
- List and use the following S.I. base quantities and their corresponding units: mass (kilogram, kg), length (metre, m), time (second, s), current (ampere, A), temperature interval (kelvin, K), amount of substance (mole, mol).
- Distinguish between base and derived quantities and units giving examples.
- Express the unit of a quantity in terms of the base units using given or standard equations or the definition of the quantity.
- Express a numerical value using the following SI prefixes: femto (f), pico (p), nano (n), micro ( $\mu$ ), milli (m), centi (c), kilo (k), mega (M) and giga (G).
- Recognise, use and express the following SI prefixes as powers of 10: femto (f), pico (p), nano (n), micro ( $\mu$ ), milli (m), centi (c), kilo (k), mega (M) and giga (G).

## 1.2 Homogeneity of physical equations

Candidates should be able to:

- Identify quantities and constants that have units and those which do not in a given equation.
- Determine if an equation is homogeneous by using base units.
- Distinguish between the concepts of physically correct and homogenous equations, giving examples of homogenous equations that are not physically correct.

## 1.3 Scalar and vector quantities

Candidates should be able to:

- Define vector and scalar quantities, giving examples of each.
- State whether a given quantity is a vector or a scalar.
- Give an example where the product of two vectors is a scalar and another when it is a vector.
- Define the resultant of a set of vectors.
- Define a sign convention or use a given sign convention to add (subtract) vectors.
- Resolve a vector into two perpendicular components.
- State and use the fact that mutually perpendicular vectors can be treated separately.
- Determine the resultant (giving both the magnitude and direction) of any set of coplanar vectors.

<b>Content</b>	<b>Learning outcomes and comments</b>
2. Mechanics	
2.1 Rectilinear motion	
2.1.1 Distance, displacement, speed, velocity and acceleration	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Distinguish between distance and displacement.</li> <li>(b) Define speed, velocity and acceleration.</li> <li>(c) Identify <math>\frac{ds}{dt}</math> as the velocity and <math>\frac{dv}{dt}</math> as the acceleration where <math>s</math> is the displacement, <math>v</math> is the velocity and <math>t</math> is the time.</li> </ul>
2.1.2 Distance (displacement)-time, speed (velocity)-time and acceleration-time graphs	<p>The candidate should be able to:</p> <ul style="list-style-type: none"> <li>(a) Draw distance (displacement)-time, speed (velocity)-time and acceleration-time graphs.</li> <li>(b) Identify which section(s) in a distance (displacement)-time graph indicate(s) a state of rest, or constant speed (velocity) or acceleration.</li> <li>(c) Identify which section(s) in a velocity-time graph indicate(s) an object moving with constant velocity, an object moving with a constant acceleration and an object moving with a variable acceleration.</li> <li>(d) Identify which section(s) in an acceleration-time graph indicate(s) an object moving at constant velocity, at constant acceleration and varying acceleration.</li> <li>(e) Determine the speed (velocity) and the average speed (velocity) from a distance (displacement)-time graph.</li> <li>(f) Determine the distance travelled, the displacement and the acceleration from a velocity-time graph.</li> <li>(g) Determine the change in velocity from an acceleration-time graph.</li> <li>(h) Relate the sign of the velocity, displacement and acceleration obtained from displacement-time and velocity-time graphs to directions specified by a sign convention.</li> </ul>
2.1.3 Equations for uniformly accelerated motion	<p>The candidate should be able to:</p> <ul style="list-style-type: none"> <li>(a) Derive the equations of uniformly accelerated motion along a straight line.</li> <li>(b) Use the equations of rectilinear motion for uniformly accelerated motion to solve problems.</li> <li>(c) Use the equations of uniformly accelerated motion to solve problems involving particles projected at any angle to the horizontal.</li> <li>(d) State the angle at which the maximum range for a given speed is attained.</li> <li>(e) State that the same horizontal range can be attained with two different angles for the same speed, provided that the range is below the maximum range.</li> </ul>
2.1.4 Experiment	<p>The candidate should be able to:</p> <ul style="list-style-type: none"> <li>(a) Describe in detail an experiment to measure the acceleration of free fall. This includes</li> </ul>

**Content****Learning outcomes and comments**

providing a diagram, the procedure, adequate precautions, measurements made and how to determine the acceleration of free fall from the graph.

## 2.1.5 Newton's first law of motion

Candidates should be able to:

- State and apply Newton's first law of motion.
- Link inertial mass with Newton's first law of motion.
- Define density.
- State the equation for density and use it to solve problems.
- Name the two fundamental forces that can act outside the nucleus.
- Draw free body diagrams. The object can be represented using a sketch or a simple shape such as a box.
- Explain what is meant by centre of mass.
- Distinguish between smooth and rough surfaces.

## 2.1.6 Newton's second law of motion.

Candidates should be able to:

- Define linear momentum.
- State Newton's second law of motion in terms of the rate of change of momentum.
- Express Newton's second law of motion as,
 
$$F = \frac{dp}{dt} = \frac{d(mv)}{dt}$$
 where  $F$  is the resultant force,  $p$  is momentum,  $m$  is mass,  $v$  is velocity and  $t$  is time.
- Derive the equation  $F = ma$ , where  $m$  is the mass taken to be constant and  $a$  is the acceleration.
- Define the newton using Newton's second law of motion.
- Write down the equation representing Newton's second law of motion and use it to solve problems where only the mass is changing or only the velocity is changing, but not both changing at the same time.
- Explain the phenomenon of apparent weightlessness for a freely falling body.

## 2.1.7 Time of impact and impulse

The candidate should be able to:

- Explain what is meant by time of impact.
- Discuss how changing the time of impact affects the force of impact.
- Define impulse.
- State and use the equation
 
$$\text{impulse} = \Delta p = F\Delta t,$$
 where  $F$  is the force and  $\Delta t$  is the time of impact.

## 2.1.8 Common forces

The candidate should be able to:

- Determine the weight of an object given its mass and the acceleration due to gravity.
- Solve simple problems involving frictional force between two surfaces that do not include the coefficient of friction.
- State and use Archimedes principle.
- Identify and use the aerodynamic lift.

**Content****Learning outcomes and comments**

## 2.1.9 Drag and terminal velocity

Candidates should be able to:

- Explain qualitatively what drag and viscosity are.
- Explain qualitatively how the drag depends on area, viscosity and velocity. Knowledge of the equations governing drag is not examinable. The candidate is only expected to be able to state if the drag decreases or increases with these quantities.
- Draw the velocity (speed)-time graph of a body falling in a viscous medium.
- State what is meant by terminal velocity (speed) and explain how this can be attained by a body falling in a viscous fluid.

## 2.1.10 Pressure

Candidates should be able to:

- Define pressure in terms of the force and the area on which it acts.
- Write down the equation  $P = \frac{F}{A}$ , where  $P$  is pressure and  $A$  is area and use it to solve problems.
- Derive the equation for hydrostatic pressure  $\rho gh$  where  $\rho$  is the density,  $g$  is the acceleration due to gravity and  $h$  is the depth.
- State the equation for hydrostatic pressure and use it to solve problems.

## 2.1.11 Newton's third law of motion

Candidates should be able to:

- State and use Newton's third law of motion.
- Identify and give examples of Newton's third law pairs of forces, i.e. the action and the reaction.

## 2.1.12 Conservation of linear momentum

Candidates should be able to:

- State the principle of conservation of linear momentum.
- Derive the principle of conservation of momentum from Newton's laws of motion.
- Solve problems using the principle of conservation of momentum in one dimension that may involve quadratic equations.
- Distinguish between perfectly elastic and inelastic collisions and determine if a given collision is perfectly elastic or inelastic.

## 2.2 Work, energy and power

## 2.2.1 Work

Candidates should be able to:

- Define mechanical work in terms of the force and the displacement in the direction of the force.
- Recognise the joule as the unit of work and energy.
- Calculate the mechanical work done by a force in a number of situations, including the work done by forces that are not in the direction of motion and by varying forces using the area under a force-displacement graph only.

<b>Content</b>	<b>Learning outcomes and comments</b>
2.2.2 Energy	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Identify and give examples of different forms of energy.</li> <li>(b) Recognise energy transformations in mechanical systems.</li> <li>(c) State and apply the principle of conservation of energy.</li> <li>(d) Distinguish between gravitational potential energy, electrical potential energy and elastic potential energy.</li> <li>(e) Recognise that the gravitational acceleration, <math>g</math>, may be assumed constant near the Earth surface.</li> <li>(f) Use the equation for gravitational potential energy changes/differences (<math>mg\Delta h</math>) near the Earth's surface where <math>\Delta h</math> is the change/difference in height.</li> <li>(g) State and use the equation for the kinetic energy (<math>\frac{1}{2}mv^2</math>). The derivation is not required.</li> </ul>
2.2.3 Power	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Define power in terms of work done and time.</li> <li>(b) Derive the equation <math>P = Fv</math> where <math>P</math> is the power, <math>F</math> is the applied force and <math>v</math> is a velocity.</li> <li>(c) State and use the equations <math>P = \frac{W}{t} = Fv</math> where <math>W</math> is the work done and <math>t</math> is the time.</li> <li>(d) Identify and use the watt as the unit of power.</li> </ul>
2.2.4 Efficiency	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Identify energy losses from a given system.</li> <li>(b) Define the efficiency of a system.</li> <li>(c) State and use the equations           <math display="block">\text{efficiency} = \frac{\text{useful output energy}}{\text{total energy input}} \times 100\%</math> <math display="block">= \frac{\text{useful power output}}{\text{total power input}} \times 100\%</math> </li> </ul>
2.3 Circular motion	
2.3.1 Kinematics of uniform circular motion	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Recognise the need of a resultant force known as the centripetal force for a particle to move at constant speed in a circular path.</li> <li>(b) Describe and explain why the motion in a curved path is due to a centripetal force in the case of uniform motion in a circle.</li> <li>(c) Explain why an object moving at a constant speed in a circular path still undergoes acceleration, known as centripetal acceleration.</li> <li>(d) Define the terms frequency and periodic time in relation to circular motion.</li> </ul>

**Content****Learning outcomes and comments**

- (e) Derive and use the equation  $v = \frac{2\pi r}{T}$ , where  $r$  is the radius and  $T$  is the periodic time.
- (f) Convert angles from degrees to radians and vice-versa.
- (g) Express angular displacement in radians.
- (h) Define angular velocity and angular speed.
- (i) State and use the equation  $v = r\omega$  where  $\omega$  is the angular velocity.
- (j) Use radians per second as the unit of angular velocity.
- (k) Convert between radians per second and revs per minute/second.
- (l) Derive the equation  $a = \frac{v^2}{r}$ , where  $a$  is the centripetal acceleration for a body moving at constant speed in a circular path.
- (m) State and use the equations  $a = \frac{v^2}{r} = r\omega^2$  to solve problems that include (but are not limited to) the following situations: the bicycle rider, motion in horizontal or vertical circles and banking of circular tracks.

## 2.4 Static Equilibrium

## 2.4.1 The turning effect of a force

Candidates should be able to:

- (a) Define the terms: moment, couple and torque (moment of a couple).
- (b) Identify force pairs which constitute a couple.
- (c) Calculate the moment of a force.
- (d) Calculate the torque produced by a couple.

## 2.4.2 Static equilibrium at a point

Candidates should be able to:

- (a) State the conditions for static equilibrium on a point object under the action of a set of coplanar forces.
- (b) Explain how equilibrium at a point is linked with Newton's first law of motion.
- (c) Solve problems involving forces in equilibrium at a point.

## 2.4.3 Static equilibrium for a rigid body

Candidates should be able to:

- (a) State and use the principle of moments.
- (b) State the conditions for static equilibrium of a rigid extended body under the action of a set of coplanar forces.
- (c) Calculate the values of unknown forces acting on a rigid body in static equilibrium under the action of a set of coplanar forces.
- (d) Define the centre of gravity.

## 2.5 Rotational dynamics

## 2.5.1 Angular acceleration

Candidates should be able to:

- (a) Define angular acceleration  $\alpha$ .
- (b) State and use the equation  $a = r\alpha$  where  $a$  is the linear tangential acceleration and  $r$  is the radial distance.

## 2.5.2 Moment of inertia

Candidates should be able to:

<b>Content</b>	<b>Learning outcomes and comments</b>
	<ul style="list-style-type: none"> <li>(a) Define moment of inertia of a rigid body.</li> <li>(b) Express the torque in terms of the moment of inertia and the angular acceleration.</li> <li>(c) Describe how the moment of inertia changes when the distribution of mass of a body changes in a simple way.</li> </ul>
2.5.3 Energy of a rigid body rotating about a fixed axis	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Identify energy changes taking place in systems involving rotating bodies.</li> <li>(b) State and use the equations for the work done, kinetic energy and power for systems involving rotating bodies.</li> <li>(c) Relate rolling without slipping to the absence of energy losses due to friction.</li> </ul>
2.5.4 Angular momentum and its conservation	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Define angular momentum in terms of moment of inertia and angular velocity.</li> <li>(b) State and use the equation <math>L = I\omega</math>, where <math>L</math> is the angular momentum.</li> <li>(c) State and use the equations for rotational motion with constant angular acceleration.</li> <li>(d) State the principle of conservation of angular momentum, identifying the necessary condition.</li> <li>(e) Use the principle of conservation of angular momentum to solve problems.</li> <li>(f) Relate variables describing angular motion to variables describing linear motion and use such relations to solve problems.</li> </ul>
3. Thermal physics	
3.1 Temperature and heat	
3.1.1 Thermal equilibrium and temperature	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Define thermal contact and thermal equilibrium.</li> <li>(b) State the Zeroth Law of thermodynamics.</li> <li>(c) Explain the relation between thermal equilibrium and temperature.</li> </ul>
3.1.2 Thermometry	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Define thermometric property.</li> <li>(b) Give examples of physical properties that may be used for the measurement of temperature.</li> <li>(c) Explain what is meant by a temperature fixed point.</li> <li>(d) Define the triple point, ice point and the steam point of water.</li> <li>(e) State and use the equation           <math display="block">\theta = \frac{X_{\theta} - X_0}{X_{100} - X_0} \times 100 \text{ } ^\circ\text{C}</math>           where <math>\theta</math> is the temperature on the Celsius scale, <math>X</math> is a thermometric property assumed to vary linearly with temperature, and subscripts indicate temperatures on the Celsius scale. Examinable thermometric properties are the length of a liquid column, the resistance of a wire or the pressure (or the corresponding         </li> </ul>

**Content****Learning outcomes and comments**

height of a column) of gas at constant volume. Ranges and structures of thermometers are not examinable.

- (f) Explain why using different thermometric properties can lead to different temperatures. Comparison of thermometers is not examinable.

- (g) State and use the equation  $T = 273.16 \frac{P}{P_{tr}}$

as  $P_{tr}$  goes to zero, where  $T$  is the thermodynamic temperature,  $P$  is the pressure at temperature  $T$  and  $P_{tr}$  is the pressure at the triple point of water.

- (h) Explain how the ideal gas temperature scale arises using the constant-volume gas thermometer and the equation

$$T = 273.16 \frac{P}{P_{tr}}.$$

The structural details of the

constant-volume gas thermometer are not required.

- (i) Relate the ideal gas temperature to the thermodynamic temperature.  
 (j) Convert between degrees Celsius and kelvin using the equation  
 $T(\text{K}) = \theta(^{\circ}\text{C}) + 273.15 \text{ K}.$   
 (k) State and use  $\Delta\theta = \Delta T.$

## 3.1.3 Heat

Candidates should be able to:

- (a) Define heat in terms of energy transfer due to a temperature difference  $\Delta T.$   
 (b) Explain how the direction of the net heat flow depends on temperature if no work is done.  
 (c) Define and use a sign convention of the candidate's choice to distinguish between heat transferred to or from the system.

## 3.1.4 Heating matter

Candidates should be able to:

- (a) Define the heat capacity  $C$  and the specific heat capacity  $c.$   
 (b) Define the mole and Avogadro's number.  
 (c) State and use the equations  $Q = C\Delta\theta$  and  $Q = mc\Delta\theta$  where  $Q$  represent the heat transferred and  $m$  is the mass.  
 (d) Describe simple experimental setups and procedures required to measure the specific heat capacity of a metal and of a liquid using an electrical heating method. The method should emphasise the conservation of energy but should not involve constant flow techniques. Identification of experimental error is expected even though the calculations of heat losses to the surroundings will not be examined.  
 (e) Define the latent heat and the specific latent heat of fusion and vaporization.  
 (f) State and use the equation  $Q = mL$  where  $L$  is the specific latent heat.  
 (g) Describe the experimental setup and procedure required to measure the latent heat

**Content****Learning outcomes and comments**

of vaporization using an electrical heating method. The method should emphasise the conservation of energy. Identification of experimental error is expected as well as accounting for heat losses using simultaneous equations.

- (h) Define molar heat capacity at constant pressure  $C_p$  and at constant volume  $C_v$  for a gas.
- (i) State and use the formulae  $Q = nC_p \Delta T$  and  $Q = nC_v \Delta T$ , where  $n$  is the number of moles.
- (j) State and use the relation  $C_p - C_v = R$ , where  $R$  is the molar gas constant.

## 3.2 Energy transfer

## 3.2.1 Energy transfer by mechanical and electrical processes

Candidates should be able to:

- (a) Determine whether work is done on (by) a system and relate this to energy transferred to (from) the system that is not due to a temperature difference.
- (b) Define and use a sign convention of the candidate's choice to distinguish between work done on or by the system.
- (c) Derive and use an equation relating the work done at constant pressure to the pressure and the change in volume.

## 3.2.2 The first law of thermodynamics

Candidates should be able to:

- (a) Define internal energy in terms of the sum of the kinetic energy and potential energy within the system.
- (b) State the first law of thermodynamics
- (c) State and use an equation representing the first law of thermodynamics identifying the symbols used.
- (d) Define and use a sign convention of the candidate's choice to distinguish between increases and decreases in internal energy.
- (e) Determine how the internal energy of a system changes with a change in temperature and with a change in phase.
- (f) Apply the first law of thermodynamics to a gas enclosed in a cylinder with moveable piston, to a heating filament, the deformation of a material and boiling of a liquid.

## 3.2.3 Isochoric, isothermal, adiabatic and isobaric processes involving gases

Candidates should be able to:

- (a) Define isochoric (isovolumetric), isothermal, adiabatic and isobaric processes
- (b) Apply the first law of thermodynamics to an isochoric (isovolumetric) process ( $\Delta W = 0$ ), an isothermal process ( $\Delta U = 0$ ), an adiabatic process ( $\Delta Q = 0$ ) and an isobaric process.

3.2.4 Pressure-volume ( $p$ - $V$ ) graphs involving gases

Candidates should be able to:

- (a) Use  $p$ - $V$  graphs to illustrate isochoric, isothermal, adiabatic and isobaric processes.

**Content****Learning outcomes and comments**

- (b) Recognize the area under a  $p$ - $V$  graph as the work done on or by a system.
- (c) State and use the equation  $PV^\gamma = \text{constant}$  for an adiabatic process where  $\gamma = \frac{C_p}{C_v}$ .

## 3.2.5 Heat engines and heat pumps

Candidates should be able to:

- (a) Define heat engine and heat pump.
- (b) Distinguish between cycles representing heat engines and those representing heat pumps using  $p$ - $V$  graphs and energy flow diagrams as appropriate.
- (c) Define the thermodynamic efficiency of a heat engine.
- (d) State and use the equation  $\eta = 1 - \frac{T_C}{T_H}$  where  $\eta$  is the maximum theoretical (Carnot) efficiency of the heat engine,  $T_C$  is the temperature of the cold reservoir and  $T_H$  is the temperature of the hot reservoir.
- (e) List factors limiting the practical efficiency of a heat engine.

## 3.2.6 Second law of thermodynamics

Candidates should be able to:

- (a) State the second law of thermodynamics in terms of a heat pump and of a heat engine.

## 3.3 Properties of ideal gases

## 3.3.1 The gas laws

Candidates should be able to:

- (a) Describe qualitatively experimental setups and corresponding procedures that can be used to investigate how the volume and the pressure of a gas changes with temperature.
- (b) Describe in detail the experimental setups and corresponding procedures that can be used to investigate how the volume of a gas changes with pressure.
- (c) State Boyle's law, Charles' Law and Gay-Lussac's (Pressure) Law together with their corresponding equations.
- (d) Derive and use the equations  $\frac{PV}{T} = \text{constant}$  and  $\frac{PV_1}{T_1} = \frac{PV_2}{T_2}$  from the gas laws, where subscripts represent different states.

## 3.3.2 Amount of substance

Candidates should be able to:

- (a) Define the molar mass, the mass number and the relative molecular mass.
- (b) Express the quantity of substance in terms of its mass, the number of moles or the number of molecules.
- (c) Use Avogadro's number to convert between the number of moles and the number of atoms.
- (d) Calculate the molar mass from the mass number or the relative molecular mass and vice-versa.

**Content****Learning outcomes and comments**

## 3.3.3 The ideal gas equation (equation of state)

Candidates should be able to:

- State and use  $k = \frac{R}{N_A}$ , where  $k$  is Boltzmann's constant and  $N_A$  is the Avogadro's constant.
- State and use the ideal gas equation as expressed in its different forms, namely  $PV = nRT$  and  $PV = NkT$ , where  $N$  is the number of molecules.
- State the conditions under which real gases behave like an ideal one.
- Discuss the limitations of the ideal gas law at very high and very low temperatures.
- Sketch the graph of  $\frac{PV}{T}$  against  $P$  for one mole of an ideal gas.
- Sketch the graph of  $\frac{PV}{T}$  against  $P$  for one mole of a typical real gas and use it to show how the quantity  $\frac{PV}{T}$  approaches the molar gas constant  $R$  as  $P$  approaches zero.

## 3.3.4 Brownian motion and molecular speeds

Candidates should be able to:

- Describe Brownian motion qualitatively and discuss how this provides experimental evidence of the random motion of gas molecules.
- Sketch the graph of the frequency distribution of molecular speeds for different temperatures. In this case the frequency is defined as the number of particles having speed between  $v$  and  $v + dv$ .
- Identify the area under a frequency distribution of molecular speeds curve as the number of particles.
- Define the mean speed, the mean square speed and the root mean square speed.

## 3.3.5 Kinetic Theory of Gases

Candidates should be able to:

- Derive and use the equation  $P = \frac{1}{3}\rho\langle c^2 \rangle$ , where  $\rho$  is the density and  $\langle c^2 \rangle$  is the mean square speed.
- List the assumptions required for  $P = \frac{1}{3}\rho\langle c^2 \rangle$  to hold.
- Relate the equation  $P = \frac{1}{3}\rho\langle c^2 \rangle$  to the ideal gas law equation  $PV = nRT$ .
- Derive and use the equation  $\langle c^2 \rangle = \frac{3RT}{M}$ , where  $M$  is the molar mass.
- Derive and use the equation  $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$ , identifying  $\frac{3}{2}kT$  as the average linear kinetic energy of a molecule within a gas and as the average energy of a particle in an ideal monatomic gas.

<b>Content</b>	<b>Learning outcomes and comments</b>
3.4 Heat transfer	
3.4.1 Heat transfer mechanisms	<p>Candidates should be able to:</p> <p>(a) Identify and describe qualitatively conduction, convection, radiation and evaporation as modes of heat transfer.</p>
3.4.2 Conduction in solids	<p>Candidates should be able to:</p> <p>(a) Describe conduction in terms of lattice vibration and free electrons in the case of metals.</p> <p>(b) List and describe the difference between good and bad conductors.</p> <p>(c) Define thermal conductivity.</p> <p>(d) State and use the equation <math>\frac{dQ}{dt} = -kA \frac{d\theta}{dx}</math> and <math>\frac{\Delta Q}{\Delta t} = kA \frac{(\theta_{\text{High}} - \theta_{\text{Low}})}{l}</math> to solve simple problems in one dimension involving a maximum of two layers. Here <math>\frac{dQ}{dt}</math> or <math>\frac{\Delta Q}{\Delta t}</math> is the rate of heat transfer with time, <math>k</math> is the thermal conductivity, <math>A</math> is an area, <math>\frac{d\theta}{dx}</math> is the rate of change of temperature with distance <math>x</math> (temperature gradient), <math>\theta_{\text{High}}</math> is the higher and <math>\theta_{\text{Low}}</math> is the lower temperature while <math>l</math> is a length.</p> <p>(e) Calculate the interface temperature.</p> <p>(f) Use the equation <math>\frac{dQ}{dt} = -kA \frac{d\theta}{dx}</math> to sketch graphs of temperature against length for a single conducting rod or two conducting rods in series with uniform cross-sectional area throughout in the steady state conditions. The rod(s) can be insulated and non-insulated.</p> <p>(g) Compare thermal and electrical conduction.</p>
3.4.3 Blackbody radiation	<p>Candidates should be able to:</p> <p>(a) Describe a blackbody in terms of its absorption and emission properties.</p> <p>(b) Explain using a diagram how a blackbody can be approximated in practice.</p> <p>(c) Sketch graphs of blackbody radiation intensity against wavelength at various temperatures.</p> <p>(d) Identify the area below a blackbody radiation intensity against wavelength curve as a measure of the total power.</p> <p>(e) State and use the inverse square law for radiation.</p>
4. Materials	
4.1 Forces, stresses and strains	<p>Candidates should be able to:</p> <p>(a) Distinguish between tensile and compressive forces.</p>

**Content****Learning outcomes and comments**

- (b) State Hooke's law in terms of force and change in length.
- (c) Define the spring/stiffness constant.
- (d) Write down Hooke's law in terms of forces and change in length and use it to solve problems.
- (e) Define stress, strain and the Young's modulus.
- (f) Write down and use the equations for stress and strain.
- (g) Write down and use Hooke's law in terms of stress and strain.
- (h) Determine the spring constant for springs connected in series or in parallel.

## 4.2 Force-extension and stress-strain graphs

Candidates should be able to:

- (a) Define the proportionality limit, the elastic limit, the yield point and the ultimate tensile strength (stress) and identify these points on force-extension and stress-strain graphs.
- (b) Define the notions of elastic behaviour, plastic behaviour, stiffness and tensile strength.
- (c) Explain how plastic behaviour leads to necking and identify the portion of force-extension and stress-strain graphs where necking occurs.
- (d) Explain how stiffness is related to the stiffness constant and to the Young's modulus.
- (e) Define brittle and ductile material and be able to identify such materials from their force-extension and stress-strain graphs.
- (f) Sketch the force-extension and stress-strain graphs of metals, rubber and brittle materials (e.g. glass).
- (g) Compare stress-strain and/or appropriate force-extension graphs to determine which materials are stiffer.
- (h) Determine the Young's modulus and the stiffness constant from force-extension and stress-strain graphs, where necessary using the original length and cross-sectional area of the wire.
- (i) Given the force-extension (strain-strain) graph of an object, determine the permanent extension (strain) the object would retain if it is extended beyond the elastic limit.
- (j) Describe the hysteresis behaviour of rubber and discuss situations where this behaviour is important.

## 4.3 Experiment(s)

The candidate should be able to:

- (a) Describe in detail an experiment to measure the Young's modulus of a metal wire. This includes providing a diagram, the procedure, adequate precautions and calculations to be made.
- (b) Describe in detail an experiment that can be used to obtain the force-extension and/or stress-strain graphs of a rubbery string for both loading and unloading in the limit where the elastic limit is not exceeded. This includes

<b>Content</b>	<b>Learning outcomes and comments</b>
	providing a diagram, the procedure, adequate precautions and calculations (if any) to be made.
4.4 Energy	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) State the equations that are valid when Hooke's law is obeyed for elastic potential energy and use them to solve problems.</li> <li>(b) State what the area under a force-extension graph represents during both loading and unloading.</li> <li>(c) Determine the work done from a force-extension graph.</li> <li>(d) Solve problems where the gravitational potential energy lost is not equal to the change in the stored elastic potential energy.</li> <li>(e) State what the area under a stress-strain graph represents during both loading and unloading.</li> </ul>
5. Electric Currents	
5.1 Charge and current	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Explain what is meant by charge carriers.</li> <li>(b) Define current as the rate of flow of charge.</li> <li>(c) Identify <math>\frac{dQ}{dt}</math> as current, where <math>Q</math> is the quantity of charge and <math>t</math> is the time.</li> <li>(d) Identify the current from the slope of a charge-time graph.</li> <li>(e) Identify the area under a current-time graph as the charge.</li> <li>(f) State and use <math>Q = It</math>, for uniform current <math>I</math>.</li> <li>(g) Distinguish between the direction of conventional current and the direction of motion of the charge carriers.</li> <li>(h) Explain how the drift speed arises.</li> <li>(i) Derive and use, for a current-carrying conductor, the expression <math>I = nAvq</math> where <math>n</math> is the number of charge carriers per unit volume, <math>A</math> is the uniform cross sectional area, <math>v</math> is the drift speed and <math>q</math> is the charge of the charge carrier.</li> </ul>
5.2 Conductors, semiconductors and insulators	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) State and explain the difference between conductors, semiconductors and insulators using the equation <math>I = nAvq</math>.</li> <li>(b) Describe schematically the basic bonding structure of the pure silicon lattice.</li> <li>(c) Distinguish between pure and impure semiconductors. The candidate should be able to describe both p-type and n-type semiconductors making reference to the impurity atoms involved in the doping.</li> <li>(d) Describe the effect of impurities on the conduction in semiconductors.</li> <li>(e) Use simple band theory to explain the differences between conductors, intrinsic and extrinsic semiconductors and insulators.</li> </ul>
5.3 Potential difference and electromotive force	<p>Candidates should be able to:</p>

**Content****Learning outcomes and comments**

- Define electrical potential difference (p.d.) in terms of the difference of the potential at two points.
- Use this definition to calculate the potential difference in a circuit.
- Relate the potential difference to the work done in moving charges between two points.
- Define electromotive force (e.m.f.) of a power supply.
- Distinguish between e.m.f. and p.d.

## 5.4 Resistances

## 5.4.1 Ohm's law

Candidates should be able to:

- Define resistance, resistivity, and conductivity.
- State Ohm's law.
- State and use  $V = IR$ , where  $V$  is the voltage and  $R$  is the resistance.

## 5.4.2 Temperature dependence of resistance

Candidates should be able to:

- State and explain the temperature dependence of resistance of metals and semiconductors.
- Define the temperature coefficient of resistance  $\alpha$ .
- Describe a simple experimental setup and procedure required to determine the temperature coefficient of resistance. Any method to measure resistance, including an ohmmeter, will be accepted. The candidate will not be expected to include the description of a null method for this experiment.

## 5.4.3 Current-voltage (I-V) characteristics

Candidates should be able to:

- Describe an experimental setup and the corresponding procedure required to investigate the I-V characteristic of an electronic component.
- Sketch and discuss the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode, a thermistor (both with a negative and a positive thermal coefficient of resistance) and a filament lamp.
- State how the resistance of a light-dependent resistor (LDR) changes with light intensity.

## 5.4.4 Internal resistance

Candidates should be able to:

- Define terminal p.d. and lost volts.
- Explain and quantify the effects of internal resistance of a power supply on the terminal p.d. Knowledge of the maximum power transfer theorem will not be examined.
- State and explain the practical importance of internal resistance in a car battery and extra-high tension supplies.
- Describe a simple experimental setup, together with the corresponding procedure required and calculations needed to determine the internal resistance of a cell. The candidate will not be expected to include the

<b>Content</b>	<b>Learning outcomes and comments</b>
	description of a null method for this experiment.
5.5 Electric circuits	
5.5.1 Circuit diagrams	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Draw the standard electronic symbols of: a wire, a cell or battery, an alternating current, a direct current power supply, an earthed point, a switch, a two-way switch, a resistor, a variable resistor, a voltmeter, an ammeter, a centre-zero galvanometer, a capacitor, a thermistor, a diode, a light dependent resistor (LDR) and a bulb.</li> <li>(b) Draw simple electrical circuits.</li> <li>(c) Use the potential divider as a variable power supply.</li> <li>(d) Explain the use of an LDR or thermistor to control voltage.</li> </ul>
5.5.2 Kirchhoff's laws	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) State Kirchhoff's first law and explain how it is linked to the conservation of charge.</li> <li>(b) State Kirchhoff's second law and explain how it is link to the conservation of energy.</li> <li>(c) Given the resistance of two or more resistors connected in series and/or in parallel, derive an expression for the combined resistance and use it to solve problems.</li> <li>(d) Derive and use the potential divider equation.</li> <li>(e) Use Kirchhoff's laws to solve circuit problems.</li> </ul>
5.5.3 The ammeter and voltmeter	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Identify the correct wiring of ammeters and voltmeters in a circuit.</li> <li>(b) Explain why an ideal ammeter has zero resistance.</li> <li>(c) Explain why an ideal voltmeter has an infinitely high resistance.</li> <li>(d) Solve circuit problems involving non-ideal ammeters and voltmeters.</li> </ul>
5.5.4 Balance of potentials and the principle of null methods	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Explain the principle of operation of the balance of potentials and the null method.</li> <li>(b) Solve problems involving the potentiometer as an ideal voltmeter. Other uses of the potentiometer will not be examined.</li> <li>(c) Identify the meter bridge within a given circuit diagram and use the relevant equations to solve the problem.</li> </ul>
5.5.5 Energy and power in D.C. circuits	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Define electrical power.</li> <li>(b) Calculate the power dissipated by different circuit components.</li> <li>(c) Define the kilowatt-hour and use it as a unit of energy.</li> <li>(d) Identify the kilowatt-hour as the unit used in the pricing of the household electrical energy consumption.</li> </ul>

<b>Content</b>	<b>Learning outcomes and comments</b>
	(e) Convert energy from joules to kilowatt-hour and vice-versa.
6. Fields	
6.1 Gravitation	
6.1.1 Newton's law of universal gravitation	<p>Candidates should be able to:</p> <p>(a) State Newton's law of universal gravitation.</p> <p>(b) Express and use Newton's law of gravitation in the form of <math>F = \frac{GMm}{r^2}</math>. Here <math>F</math> is the gravitational force between two bodies of gravitational masses <math>M</math> and <math>m</math>, <math>r</math> is the distance between their centres, while the constant of proportionality <math>G</math> is known as the universal gravitational constant.</p> <p>(c) Relate the gravitational force to the weight.</p>
6.1.2 Gravitational field strength	<p>Candidates should be able to:</p> <p>(a) Define gravitational field in terms of a region of space where the gravitational force acts.</p> <p>(b) State the direction of the gravitational field lines.</p> <p>(c) Draw the gravitational field lines including the direction, and equipotential surfaces for radial and uniform gravitational fields.</p> <p>(d) Define gravitational field strength (intensity).</p> <p>(e) State and use the equation <math>g = \frac{GM}{r^2}</math>, where <math>g</math> is the gravitational field strength (intensity).</p> <p>(f) Describe and show using a graph how the gravitational field strength varies with distance from the Earth's centre. Only the variation above the Earth's surface will be examined.</p> <p>(g) List and explain the factors that cause variations of the gravitational field strength over the Earth's surface.</p> <p>(h) Describe and calculate the effect of the rotation of a planet on the measured acceleration due to gravity. Only differences between the measured values of the acceleration due to gravity at a pole and at the equator of the planet will be examined.</p> <p>(i) Distinguish between gravitational and inertial mass.</p> <p>(j) Link the gravitational field strength (intensity) to the acceleration due to gravity.</p>
6.1.3 Gravitational potential energy	<p>Candidates should be able to:</p> <p>(a) Define gravitational potential and gravitational potential energy at a point.</p> <p>(b) State and use the equation <math>W = mV</math> where <math>W</math> is the work done and <math>V</math> is the gravitational potential difference.</p> <p>(c) State and use the equation <math>V = -\frac{GM}{r}</math>, where <math>V</math> is the gravitational potential.</p> <p>(d) State and use the equation <math>g = -\frac{dV}{dr}</math>.</p>

<b>Content</b>	<b>Learning outcomes and comments</b>
	(e) Define the escape velocity from the surface of a body. (f) Derive and use an expression for the escape velocity from the surface of a body in terms of a given set of quantities.
6.1.4 Satellites	Candidates should be able to: (a) Identify the gravitational force acting on a satellite as a centripetal force. (b) Derive and use the equation $v^2 = \frac{GM}{r}$ for a satellite moving in a circular orbit with a velocity $v$ and a periodic time $T$ . (c) Show that for a satellite $T^2 \propto r^3$ . (d) Define geostationary orbit. (e) State and explain the conditions for a satellite to move in a geostationary orbit. (f) Explain the phenomenon of apparent weightlessness for an orbiting body.
6.2 Electrostatic fields	
6.2.1 Simple electrostatics phenomena	Candidates should be able to: (a) State the conditions for electrical attraction and repulsion between charges. (b) Describe how to charge an insulator by friction. (c) Describe how to charge a metal by induction.
6.2.2 Coulomb's law of electrostatics	Candidates should be able to: (a) State Coulomb's law of electrostatics. (b) Express and use Coulomb's law of electrostatics in the form $F = \frac{Qq}{4\pi\epsilon r^2}$ . Here $F$ is the electrostatic force between two point objects having charges $Q$ and $q$ at a distance $r$ apart, while $\frac{1}{4\pi\epsilon}$ is the constant of proportionality known as the Coulomb's constant with $\epsilon$ being the permittivity of the surrounding medium. (c) Distinguish between the permittivity and the permittivity of free space $\epsilon_0$ . (d) Define the relative permittivity (dielectric constant) $\epsilon_r$ . (e) Use the coulomb as the unit of charge.
6.2.3 Electric field strength	Candidates should be able to: (a) Define electric field in terms of a region of space where the electric force acts. (b) Define the direction of the lines of force of an electrostatic field. (c) Use lines of force and equipotentials to describe electric fields qualitatively. (d) Draw the lines of force, including the direction, for a radial field, for a uniform field and for the field between two point charges of equal magnitude in vacuum. (e) Define the electric field strength at a point.

**Content****Learning outcomes and comments**

- (f) State and use the equation  $E = \frac{F}{q}$ , where  $E$  is the electric field strength,  $F$  is the force due to the electric field and  $q$  is the charge.
- (g) State and use the equation  $E = \frac{Q}{4\pi\epsilon r^2}$  for a point charge.
- (h) Solve problems involving the acceleration of a charged particle moving in a uniform electric field with the initial velocity being parallel or perpendicular to the lines of force.
- (i) List the similarities and differences between electric and gravitational fields.
- (j) State the magnitude of the electrostatic field strength inside a hollow charged conductor.

## 6.2.4 Electric potential

Candidates should be able to:

- (a) Define electrostatic potential.
- (b) State and use the equation  $W = qV$  where  $W$  is the work done and  $V$  is the potential difference.
- (c) State and use the equation  $V = \frac{Q}{4\pi\epsilon r}$  for a radial field.
- (d) Determine the potential difference between two points.
- (e) Link the electric field strength to the gradient of the potential.
- (f) State and use the equation  $E = -\frac{dV}{dr}$ , where  $V$  is potential and  $r$  is distance.
- (g) State and use the equation  $V = Ed$ , where  $E$  is the electric field strength of a uniform electric field,  $V$  is the potential difference and  $d$  is the distance between the points.
- (h) State and use the equation  $Vq = \Delta K.E.$  where  $\Delta K.E.$  is the change in kinetic energy and  $V$  is the potential difference.
- (i) Define the electronvolt and use it as a unit of energy.
- (j) Use the value of the electric field and the equation  $E = -\frac{dV}{dr}$  to explain why the potential inside a hollow charged conductor is constant.

## 6.3 Capacitors

## 6.3.1 Capacitance

Candidates should be able to:

- (a) Define the capacitance of a capacitor.
- (b) State and use the equation  $Q = CV$  where  $V$  is the potential difference and  $C$  the capacitance.
- (c) Use farads as the unit of capacitance.

## 6.3.2 The parallel plate capacitor

Candidates should be able to:

- (a) Sketch a well labelled diagram of the basic structure of a parallel plate capacitor.

**Content****Learning outcomes and comments**

- (b) List the factors on which the capacitance of a parallel plate capacitor depends and discuss how the capacitance will change when one of these factors is varied.
- (c) State and use the equation  $C = \frac{\epsilon A}{d} = \frac{\epsilon_r \epsilon_0 A}{d}$ , where  $A$  is the area of overlap and  $d$  is the distance between the plates.
- (d) Derive and use the relation  $\epsilon_r = \frac{C}{C_0}$ , where  $C$  is the capacitance for a general dielectric and  $C_0$  is the capacitance when vacuum is the dielectric.

## 6.3.3 Dielectric

Candidates should be able to:

- (a) Describe how the polarisation of the dielectric affects the capacitance.
- (b) Define the dielectric strength.
- (c) Identify  $\text{V m}^{-1}$  as a unit of the dielectric strength.
- (d) Distinguish between operating and breakdown voltage.
- (e) Explain what is meant by leakage current.

## 6.3.4 The electrolytic capacitor

Candidates should be able to:

- (a) Sketch a well labelled diagram of the structure of an electrolytic capacitor and describe qualitatively the formation of the dielectric.
- (b) List the advantages and disadvantages of electrostatic capacitors.

## 6.3.5 Charging and discharging of capacitors through resistors

Candidates should be able to:

- (a) Draw a diagram of a circuit that can be used to study the charging and the discharging of a capacitor using a two way switch and other components such as resistors, voltmeters and ammeters.
- (b) Draw graphs of charge stored, voltage and current against time obtained when charging and discharging a capacitor through a resistor.
- (c) Describe the change in charge stored on, voltage across and current through a capacitor when discharging the capacitor through a resistor as an exponential decay and relate it to radioactive decay.
- (d) State and use the equations  $Q = Q_0 e^{-\frac{t}{RC}}$  and  $Q = Q_0 \left(1 - e^{-\frac{t}{RC}}\right)$  where  $Q_0$  is the maximum charge,  $Q$  is the charge at time  $t$ ,  $R$  is the resistance and  $C$  is the capacitance.
- (e) Use the equations for charge to obtain and then use the equations  $V = V_0 e^{-\frac{t}{RC}}$ ,  $I = I_0 e^{-\frac{t}{RC}}$  and  $V = V_0 \left(1 - e^{-\frac{t}{RC}}\right)$  where  $V_0$  is the maximum voltage,  $I_0$  is the initial current

<b>Content</b>	<b>Learning outcomes and comments</b>
	<p>while <math>V</math> and <math>I</math> are respectively the voltage and current at time <math>t</math>.</p> <p>(f) Use logarithms to manipulate the equations for charging and discharging.</p>
6.3.6 Time constant	<p>Candidates should be able to:</p> <p>(a) Define the time constant.</p> <p>(b) Use the graphs for charging and discharging of a capacitor through a resistor to obtain the time constant.</p> <p>(c) State and use the equation <math>T = RC</math>, where <math>T</math> is the time constant.</p> <p>(d) Determine the charge in and voltage across a capacitor, as well as the corresponding current in the circuit, after a time period equal to an integral multiple of the time constant.</p> <p>(e) Sketch graphs of charge stored in and voltage across a capacitor against time when charging and discharging capacitors for different values of the time constant.</p>
6.3.7 Capacitors in series and in parallel	<p>Candidates should be able to:</p> <p>(a) Derive and use expressions for the total capacitance of a number of capacitors connected in series and/or in parallel.</p>
6.3.8 Energy stored in a capacitor	<p>Candidates should be able to:</p> <p>(a) Determine the energy stored in a capacitor from the area under a charge-voltage graph.</p> <p>(b) State and use the equation <math>W = \frac{1}{2} QV</math>, where <math>W</math> is the energy.</p>
6.4 Magnetic fields	
6.4.1 Magnetic field	<p>Candidates should be able to:</p> <p>(a) Define magnetic field in terms of a region of space where the magnetic force acts.</p> <p>(b) Define the direction of the magnetic field lines.</p> <p>(c) Draw the magnetic field lines due to a bar magnet, a North and a South pole facing each other, a long straight current-carrying conductor, two long straight parallel conductors carrying equal currents and a solenoid. Where appropriate the magnetic polarity should be indicated. Use of mnemonics, such as the right hand grip rule, to indicate relative direction of quantities and magnetic polarity is expected.</p> <p>(d) Use standard symbols (such as <math>\otimes</math> and <math>\times</math>) to indicate current and magnetic field lines direction relative to the plane in a two dimensional diagram.</p>
6.4.2 Magnetic flux density, flux and flux linkage	<p>Candidates should be able to:</p> <p>(a) Define magnetic flux density <math>B</math>, flux <math>\phi</math> and flux linkage <math>N\phi</math> where <math>N</math> is the number of turns.</p> <p>(b) Use the weber as the unit for magnetic flux.</p> <p>(c) Identify the magnetic flux density as a vector quantity.</p>

**Content**

6.4.3 Magnetic flux density of a wire and a solenoid

**Learning outcomes and comments**

Candidates should be able to:

- (a) State and use the equation  $B = \frac{\mu_0 I}{2\pi r}$  where  $I$

is the current,  $r$  is the distance,  $\mu_0$  is the permeability of free space and  $B$  is the magnetic flux density around a current-carrying conductor.

- (b) Describe an experimental setup and

procedure to verify the equation  $B = \frac{\mu_0 I}{2\pi r}$ .

The value of  $B$  is measured using a Hall probe.

- (c) State and use the equation  $B = \mu_r \mu_0 nI$  where  $n$  is the number of turns per unit length,  $\mu_r$  is the relative permeability and  $B$  is the magnetic flux density inside a long solenoid.
- (d) Describe the experimental setup and procedure to verify the equation  $B = \mu_0 nI$ . The value of  $B$  is measured using a Hall probe.

6.4.4 Magnetic force on a current-carrying conductor

Candidates should be able to:

- (a) Relate the magnetic force on a current carrying conductor to the magnetic flux density.
- (b) State and use the equation  $F = BIl \sin(\theta)$  where  $F$  is the force,  $I$  the current,  $l$  the length of the conductor and  $\theta$  is the angle between the directions of the magnetic flux density and the current.
- (c) Use Fleming's left hand rule or any other equivalent rule.
- (d) Define the tesla and use it as the unit for the magnetic flux density.

6.4.5 Force between two long parallel current-carrying straight conductors

Candidates should be able to:

- (a) Obtain and use the equation for the force between two long parallel current-carrying straight conductors.
- (b) Identify the forces between two long parallel current-carrying straight conductors as a Newton third law pair.
- (c) Define the ampere and use it as the unit for electric current.

6.4.6 Force on a charged particle moving through a magnetic field

Candidates should be able to:

- (a) Derive and use the equation  $F = Bqv \sin(\theta)$  where  $q$  is the charge,  $v$  is the velocity and  $\theta$  is the angle between  $B$  and  $v$ .
- (b) Relate the direction of the force to that of a charged particle in motion and the magnetic field.
- (c) Identify the magnetic force on a charged particle moving in a plane perpendicular to that of a uniform magnetic field as a centripetal force.
- (d) Derive and use  $mv = Bqr$  where  $m$  is the mass and  $r$  is the radius of the path.

<b>Content</b>	<b>Learning outcomes and comments</b>
6.4.7 Torque on a rectangular coil in a uniform and a radial magnetic field	<p>Candidates should be able to:</p> <p>(a) Derive and use the equation <math>\tau = BANl \cos(\theta)</math> where <math>\tau</math> is the torque, <math>N</math> is the number of turns and <math>\theta</math> is the angle between the plane of the coil and the magnetic field.</p>
6.4.8 The Hall Effect and the Hall probe	<p>Candidates should be able to:</p> <p>(a) Describe the Hall Effect.</p> <p>(b) Derive and use the equation <math>V_H = \frac{BI}{nqt}</math> where <math>V_H</math> is the Hall voltage, <math>n</math> is the volume density of the mobile charge, <math>q</math> the charge and <math>t</math> is the thickness.</p> <p>(c) Explain how measurement of the Hall voltage can be used to determine the magnetic flux density.</p> <p>(d) Describe in detail the experimental setup and procedure required to calibrate, i.e. determine <math>nqt</math>, a Hall probe.</p> <p>(e) Describe how to measure a magnetic field using a Hall probe. This should include the positioning of the Hall probe in the magnetic field as well as the details of the external circuit.</p>
6.4.9 Crossed electric and magnetic fields that are at right angles to each other	<p>Candidates should be able to:</p> <p>(a) Solve problems involving electric and magnetic fields that are at right angles to each other.</p> <p>(b) Explain how crossed electric and magnetic fields are used to separate ions of different masses in a mass spectrometer.</p> <p>(c) Relate the charge to mass ratio to the deflection of an ion in a mass spectrometer.</p>
6.4.10 Physical principles of a cyclotron	<p>Candidates should be able to:</p> <p>(a) Relate the charge to mass ratio to the energy required to accelerate a charged particle.</p> <p>(b) Identify the speed of light as the limiting speed for accelerating particles and relate this qualitatively to the energy required.</p> <p>(c) Explain the physical principles a cyclotron that allow particles to be accelerated to very large speeds.</p> <p>(d) Derive and use the non-relativistic expression for the cyclotron supply frequency.</p>
6.5 Electromagnetic induction	
6.5.1 Magnetic flux and flux linkage	<p>Candidates should be able to:</p> <p>(a) Describe a simple experimental setup using a solenoid and a magnet together with the corresponding procedure required to investigate how the rate of change of flux induces an electromotive force (e.m.f.) in a circuit, reporting the observations made. Only the qualitative analysis of the observations will be examined.</p>

**Content**

6.5.2 Faraday's and Lenz's laws of electromagnetic induction

**Learning outcomes and comments**

Candidates should be able to:

- State Faraday's and Lenz's laws of electromagnetic induction.
- Relate Lenz's law to energy conservation.
- State and use the equation  $E = -\frac{d(N\phi)}{dt}$  where  $N$  is the number of turns,  $\phi$  is the flux, the produce  $N\phi$  is the flux linkage and  $E$  is the induced e.m.f.
- Starting from Faraday's law, derive and use the equation  $E = Blv$  where  $l$  is the length of the conductor and  $v$  the velocity. The quantities  $B$ ,  $l$  and  $v$  are to be taken perpendicular to each other.
- Describe qualitatively an experimental setup and procedure required to verify Lenz's law.
- Identify instances where Lenz's law is necessary to explain the behaviour of a system.
- Relate the directions of the magnetic field, current and the motion of the conductor in a simple generator. Use of Fleming's right hand rule is expected.
- Determine the polarity at the ends of a conductor due to an induced e.m.f.

6.5.3 Back e.m.f. in electric motors

Candidates should be able to:

- Explain how back e.m.f. is produced in electric motors.
- Explain the implications of back e.m.f. in electric motors.
- Calculate and use the back e.m.f. in simple electric motors.

6.5.4 Mutual inductance and self-inductance

Candidates should be able to:

- Describe qualitatively the experimental setup and procedure required to investigate how self-induction affects the growth and decay of current in d.c. circuits and in the choking of an a.c. current.
- Define self-inductance  $L$  and mutual inductance  $M$ .
- Define the henry and use it as the unit of inductance.
- State and use the equations  $E_2 = -M \frac{dI_1}{dt}$  and  $E_1 = -L \frac{dI_1}{dt}$ .
- State and use the equation  $W = \frac{1}{2} LI^2$  where  $W$  is the energy stored in the magnetic field of the inductor and  $I$  is the current.

6.5.5 Transformers

Candidates should be able to:

- Sketch the basic structure of a transformer and explain how it works.
- Identify an iron core and laminations as structural features of the transformer that may increase its efficiency.
- State and use the ideal transformer equations.

**Content****Learning outcomes and comments**

## 6.5.6 Growth and decay of current in inductive circuits

- (d) Explain why and how transformers are employed in the transmission of electricity from the generating stations to the consumers.

Candidates should be able to:

- (a) Sketch graphs of current against time to show how the current grows and decays in inductive circuits.
- (b) Relate the current growth and decay in inductive circuits to Lenz's law.
- (c) State and use the equations  $E - L \frac{dI}{dt} = IR$  where  $R$  is the resistance. Problems with the current depending on exponential terms will not be set.
- (d) Explain why the back e.m.f. induced in a coil when switching off can be larger than the supply e.m.f.

## 6.5.7 Simple alternating current generator

Candidates should be able to:

- (a) Sketch the basic structure of a simple generator consisting of a rectangular coil rotating in a uniform magnetic field and explain why an e.m.f. is induced.
- (b) Sketch the graphs of the output e.m.f. and current, relating the variation to those of oscillations.
- (c) State and use the equation  $V = V_0 \sin(\omega t + \phi)$  where  $V_0$  is the peak induced e.m.f.,  $V$  is the induced e.m.f. at time  $t$  while  $\phi$  is a phase shift.
- (d) State and use  $V_0 = BAN\omega$ , where  $B$  is the magnetic field,  $A$  is the area,  $N$  is the number of turns and  $\omega$  is the angular frequency.

## 6.6 Alternating current (a.c.)

## 6.6.1 Peak and root mean square values for a sinusoidal alternating current

Candidates should be able to:

- (a) Define the peak and root mean square value of the voltage  $V$  and current  $I$  of a sinusoidal alternating current.
- (b) State and use the equations  $I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$  and  $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$  where  $I_0$  and  $V_0$  are respectively the peak current and voltage while  $I_{\text{rms}}$  and  $V_{\text{rms}}$  are the corresponding rms current and voltage.

## 6.6.2 Reactance

Candidates should be able to:

- (a) Explain the phenomenon of reactance which arises when a capacitor or/and an inductor are in a circuit with an alternating current supply.
- (b) Quantify the "opposition" to an alternating current by an inductor or capacitor, that is the reactance, as the ratio of  $V_{\text{rms}}$  to  $I_{\text{rms}}$ .
- (c) Distinguish between the reactance and the electrical resistance, with particular reference

<b>Content</b>	<b>Learning outcomes and comments</b>
	to the former's dependency on the frequency of the a.c.
	(d) State and use the equation $X_C = \frac{1}{2\pi fC}$ to solve problems restricted to purely capacitive components, where $X_C$ is the reactance due to a pure capacitor of capacitance $C$ and $f$ is the frequency.
	(e) State and use the equation $X_L = 2\pi fL$ to solve problems restricted to purely inductive components where $X_L$ is the reactance due to a pure inductor of inductance $L$ .
	(f) Explain why no power is dissipated across a pure capacitor and a pure inductor.
6.6.3 Oscilloscopes	Candidates should be able to: (a) Relate the output on the screen of an oscilloscope to the peak voltage and to time intervals using the voltage sensitivity and time base respectively.
6.6.4 The p-n junction diode	Candidates should be able to: (a) Draw a current-voltage graph for a p-n junction diode. This includes both the forward and reverse bias characteristics. (b) Identify the leakage current, the breakdown voltage and the barrier p.d. on a current-voltage graph for a p-n junction diode. (c) Explain how a p-n junction diode works making reference to majority and minority charge carriers, the depletion layer and the barrier p.d.
6.6.5 Half-wave and full-wave rectification circuits	Candidates should be able to: (a) Define a.c. rectification. (b) Draw the circuits for a half-wave rectifier and a full-wave bridge rectifier. (c) Explain how capacitors can be combined with half-wave and full-wave rectification circuits to smooth their output. (d) Given an input sinusoidal a.c. signal, sketch the corresponding output voltage-time graphs for half-wave and full-wave rectification, with and without smoothing.
7. Vibrations and waves	
7.1 Simple harmonic motion	
7.1.1 Definitions and equations	Candidates should be able to: (a) Define periodic time, frequency, angular frequency, amplitude, equilibrium (rest) position and restoring force. (b) Identify the resultant force acting on a particle performing simple harmonic motion as the restoring force. (c) State and use the equations $T = \frac{1}{f}$ and $\omega = 2\pi f$ where $\omega$ is the angular frequency, $T$ is the periodic time and $f$ is the frequency.

**Content****Learning outcomes and comments**

	<ul style="list-style-type: none"> <li>(d) Define simple harmonic motion.</li> <li>(e) State and use the equation <math>a = -\omega^2 x</math> where <math>a</math> is the acceleration, <math>x</math> is the displacement from the equilibrium position and <math>\omega</math> is the angular frequency.</li> <li>(f) Recognise <math>a = -\omega^2 x</math> as the equation that defines simple harmonic motion.</li> <li>(g) State and use the equation <math>v = \pm\omega\sqrt{x_0^2 - x^2}</math> where <math>v</math> is the velocity and <math>x_0</math> the amplitude.</li> </ul>
7.1.2 Acceleration-displacement graph	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Sketch the acceleration-displacement graph.</li> <li>(b) Determine the angular frequency from the acceleration-displacement graph.</li> </ul>
7.1.3 Displacement-time, velocity-time and acceleration-time graphs	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Sketch the corresponding displacement-time, velocity-time, and acceleration-time graphs. The initial conditions can be that at the initial time the system starts either from zero or from the maximum absolute value.</li> <li>(b) Determine the amplitude and periodic time from a given displacement-time graph.</li> <li>(c) Determine the maximum velocity and periodic time from a given velocity-time graph.</li> <li>(d) Determine the maximum acceleration and periodic time from a given acceleration-time graph.</li> </ul>
7.1.4 Phase	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Explain what is meant by motion in-phase, anti-phase and out of phase.</li> <li>(b) Determine the phase difference between two simple harmonic oscillators. The phase difference can have any value between 0 and <math>2\pi</math>.</li> <li>(c) Explain the meaning of phase lead and phase lag.</li> <li>(d) State and use the equations <math>x = x_0 \sin(\omega t + \phi)</math>, <math>v = \omega x_0 \cos(\omega t + \phi)</math>, and <math>a = -\omega^2 x_0 \sin(\omega t + \phi)</math>, where <math>t</math> is time and <math>\phi</math> the phase difference. The corresponding equations involving a phase shift of <math>\frac{1}{2}\pi</math> can also be examined.</li> </ul>
7.1.5 Relation to circular motion	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Relate simple harmonic motion to circular motion.</li> <li>(b) Relate the angular frequency to the angular velocity.</li> </ul>
7.1.6 Energy in simple harmonic motion	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Sketch the kinetic energy-displacement, potential energy-displacement and total energy-displacement graphs.</li> <li>(b) State and use the equations <math>K.E. = \frac{1}{2}m\omega^2(x_0^2 - x^2)</math>, <math>E_{\text{Total}} = \frac{1}{2}m\omega^2 x_0^2</math> and</li> </ul>

<b>Content</b>	<b>Learning outcomes and comments</b>
	<p>P.E. = <math>\frac{1}{2}m\omega^2x^2</math>, where K.E. is the kinetic energy, <math>E_{\text{Total}}</math> is the total energy, P.E. is the potential energy and <math>m</math> is the mass.</p>
7.1.7 Examples of systems performing simple harmonic motion	<p>Candidates should be able to:</p> <ol style="list-style-type: none"> <li>Show that a mass-spring system performs simple harmonic motion.</li> <li>Derive the equation for the periodic time of a mass-spring system.</li> </ol>
7.1.8 Free and damped vibrations	<p>Candidates should be able to:</p> <ol style="list-style-type: none"> <li>Explain what is meant by free oscillations.</li> <li>Define natural frequency or frequencies.</li> <li>Distinguish between light (under), critical and heavy (over) -damping, giving one practical example of each.</li> <li>Sketch displacement-time graphs for light (under), critical and heavy (over) -damping.</li> </ol>
7.1.9 Forced vibrations and resonance	<p>Candidates should be able to:</p> <ol style="list-style-type: none"> <li>Explain what is meant by forced vibrations and forcing frequency.</li> <li>Distinguish between the driver and the driven oscillating system.</li> <li>Explain the terms resonance and resonant frequency.</li> <li>Give examples where resonance is useful and others where it is undesirable.</li> <li>Describe an experiment that shows how the amplitude of a driven oscillating system with the forcing frequency.</li> <li>Sketch how the amplitude of a forced oscillator changes with the driving frequency, i.e. the resonance curve.</li> <li>Explain how the resonance curve changes with increasing damping. Changes in the resonant frequency due to damping will not be examined.</li> </ol>
7.2 Waves	
7.2.1 Progressive waves	<p>Candidates should be able to:</p> <ol style="list-style-type: none"> <li>Explain what is meant by a progressive wave.</li> <li>Explain what is meant by a mechanical wave.</li> <li>Define crest, trough, amplitude, periodic time, frequency, angular frequency and wavelength as applied to mechanical waves.</li> <li>Relate the amplitude, frequency, angular frequency and periodic time of waves to those of the simple harmonic motion of particles in the medium.</li> <li>State and use the equation <math>v = f\lambda</math>, where <math>v</math> is the speed of propagation, <math>f</math> is the frequency and <math>\lambda</math> is the wavelength.</li> </ol>
7.2.2 Displacement-position and displacement-time graphs.	<p>Candidates should be able to:</p> <ol style="list-style-type: none"> <li>Sketch the displacement-position and displacement-time graphs for a progressive wave.</li> <li>Determine the amplitude and the wavelength from a displacement-position graph.</li> </ol>

**Content****Learning outcomes and comments**

- (c) Determine the amplitude and the periodic time from a displacement-time graph.
- (d) Use the displacement-time and displacement-position graphs to determine the phase difference between two.
- (e) State and use the equation  $\phi = \frac{2\pi x}{\lambda}$  where  $\phi$  is the phase difference between two points in a wave separated by a distance  $x$ .
- (f) State and identify the equation  $y = A \sin\left(\omega t \pm \frac{2\pi}{\lambda} x\right)$  and its alternative forms as the progressive wave equation, where  $y$  is the displacement at a point  $x$ ,  $t$  is the time, and  $A$  is the amplitude.

## 7.2.3 Longitudinal and transverse progressive waves

Candidates should be able to:

- (a) Define longitudinal and transverse waves.
- (b) Give examples of transverse waves, including water surface waves and waves on slinky springs.
- (c) Give examples of longitudinal waves, including sound waves and waves along slinky springs.
- (d) Interpret the displacement-position graphs for transverse and longitudinal waves.
- (e) Identify the position of compressions and rarefactions from displacement-position graphs representing longitudinal waves.
- (f) Sketch the pressure-position graph for longitudinal waves.

## 7.2.4 The speed of sound

Candidates should be able to:

- (a) Describe in detail the progressive wave method for the determination of the wavelength of sound and consequently the speed of sound in air. This includes providing a diagram, the procedure, adequate precautions and any calculations made.

**Content****Learning outcomes and comments**

## 7.2.5 Electromagnetic waves

Candidates should be able to:

- List the various regions of the electromagnetic spectrum giving a representative wavelength for each.
- List the colours in the visible spectrum in increasing or decreasing wavelength order.
- State the range of wavelengths of the visible spectrum (400 nm to 700 nm).
- Give a source, a mode of detection as well as the uses of waves within each region of the electromagnetic spectrum.
- Describe experiments to show that visible light obeys the laws of reflection and refraction.
- Describe an experimental setup and the corresponding procedure to determine the refractive index of a transparent solid.
- Describe a method to demonstrate the reflection and refraction of microwaves. This includes providing a diagram and the procedure.

## 7.2.6 Plane polarisation

Candidates should be able to:

- Explain what is meant by plane polarisation.
- Describe in detail an experiment to demonstrate how microwaves and visible light can be plane polarised. This includes providing a diagram, the procedure and observations made.

## 7.3 Superposition of waves

## 7.3.1 The principle of superposition and the formation of stationary (standing) waves

Candidates should be able to:

- State the principle of superposition of pulses and waves.
- State the conditions for stationary waves. It should be assumed that the stationary waves are planar and complete cancellation occurs at the nodes.
- Identify the formation of standing waves in a given system. Examinable situations will involve either two generators of waves or a generator of waves and reflector. Questions involving open ends will not be set.
- Use displacement-position graphs to explain how nodes and antinodes are formed.
- Define nodes and antinodes.
- Identify nodes, antinodes and loops in a given standing wave.
- Identify and calculate the wavelength in a stationary wave.
- Distinguish between progressive and standing waves in terms of the amplitude, phase relationship, the propagation of the wave profile and energy as applied to a sinusoidal wave.

## 7.3.2 Standing waves on a string

Candidates should be able to:

- Identify vibrating strings as a system that can resonate at various frequencies.

**Content****Learning outcomes and comments**

- (b) Describe in detail Melde's experiment or a similar experiment involving an oscillator to demonstrate the formation of stationary waves in strings and to investigate the relationship between the frequency  $f_n$  of the  $n^{\text{th}}$  harmonic, the length  $L$  of the string that is free to vibrate, the tension force  $T$  in the string and the mass per unit length  $\mu$  of the string. This includes providing a diagram, the procedure, observations and measurements made.
- (c) Describe qualitatively how a standing wave can be formed on a stretched string.
- (d) State and use the equations  $f_n = \frac{n}{2L} \sqrt{\frac{T}{\mu}}$  and  $v = \sqrt{\frac{T}{\mu}}$  where  $v$  is the speed.

## 7.3.3 Diffraction of water waves at a gap

Candidates should be able to:

- (a) Describe an experiment to investigate the diffraction of water waves at a gap. This includes providing a diagram and observations made.
- (b) Explain and sketch how the diffraction pattern would change as the width of the gap and the wavelength are varied.

## 7.3.4 Diffraction of visible light and microwaves at a single slit (rectangular aperture)

Candidates should be able to:

- (a) Describe an experiment to investigate the diffraction of microwaves at a single slit. This includes providing a diagram and observations made.
- (b) Describe an experiment to investigate the diffraction of visible light at a single slit. This includes providing a diagram and observations made.
- (c) Explain and sketch how the pattern would change as the width of a rectangular aperture and the wavelengths are varied.
- (d) State and use the equation  $\sin(\theta) \approx \theta = \frac{\lambda}{a}$  to solve problems as well as to describe and explain the behaviour of waves at a single slit, where  $a$  is the width of a rectangular aperture,  $\lambda$  is the wavelength and  $\theta$  is the angular distance between the normal and the first minimum that is measured in radians.
- (e) Sketch the intensity graph for a single rectangular aperture.

## 7.3.5 Resolving power of instruments

Candidates should be able to:

- (a) Discuss how the diameter of a circular aperture and the wavelength of the incident wave affect the resolving power of an instrument.
- (b) State and use the equation  $\sin(\theta) \approx \theta = 1.22 \frac{\lambda}{a}$  where  $a$  is the diameter

**Content**

## 7.3.6 Interference of waves from two coherent point sources

## 7.3.7 Young's double-slit experiment using visible light

## 7.3.8 Optical diffraction grating

**Learning outcomes and comments**

and  $\theta$  is the angle between the normal and the first diffraction minimum.

- (c) Explain what is meant by resolving power of an instrument.
- (d) State and use Rayleigh's criterion for an instrument with a circular aperture.
- (e) Explain how the resolving power of an instrument with a circular aperture changes with wavelength and diameter.

Candidates should be able to:

- (a) Explain what is meant by two coherent sources.
- (b) Sketch the resulting wavefronts to describe qualitatively the regions of constructive and destructive interference of waves originating from two coherent point sources.
- (c) Explain what is meant by path difference and express the path difference as a multiple of the wavelength.
- (d) Determine the phase difference at a point taking into account the path difference, the initial phase relationship between the sources and any other phase change.
- (e) State and use the conditions for constructive and destructive interference in terms of the phase difference.
- (f) Describe how the interference pattern arising from waves emitted from two point sources relates to the phase differences.
- (g) Describe qualitatively how the interference pattern would change if the source separation and the wavelength are changed.

Candidates should be able to:

- (a) Define monochromatic light.
- (b) Describe in detail Young's double-slit experiment for visible light and use it as experimental evidence of the wave nature of light. This includes providing a diagram, the procedure and observations made.
- (c) State typical length scales that are used in Young's double-slit experiment.
- (d) Sketch the interference pattern (fringes) observed on a screen in Young's double slit experiment.
- (e) Identify the central (zeroth order) bright fringe and the  $n^{\text{th}}$  order bright (dark) fringes.
- (f) State the conditions for the interference pattern to be observable.
- (g) State how the pattern would change if the slit separation, wavelength and distance between the slits and the screen are changed.
- (h) Sketch the intensity graph for a double-slit.
- (i) State and use the equation  $y = \frac{\lambda D}{d}$ , where  $y$  is the fringe separation,  $\lambda$  is the wavelength,  $d$  is the slit separation and  $D$  is the distance between the double-slits and the screen.

Candidates should be able to:

- (a) Describe what a diffraction grating is.

**Content****Learning outcomes and comments**

- (b) State and use the equation  $d = \frac{1}{N}$  where  $d$  is the grating spacing and  $N$  is the number of lines per unit length.
- (c) State and use the equation  $d \sin(\theta_n) = n\lambda$ , where  $\theta_n$  is the angular separation between the normal and the  $n^{\text{th}}$  order spectral line (image).
- (d) Explain how the pattern changes when the wavelength is changed and when more than one wavelength (including white light) is used.
- (e) Compare the spectra produced by a diffraction grating with that produced by a prism.
- (f) Describe in detail an experiment involving a spectrometer and a diffraction grating to measure the wavelength. This includes providing a diagram, the procedure, the measurements and the calculations made. Details of the adjustments to the spectrometer will not be examined.

## 7.4 Optics

## 7.4.1 Light incident on a boundary and reflection

Candidates should be able to:

- (a) List the processes that can take place when light is incident on a boundary between two media - namely reflection, refraction (transmission) and absorption - and distinguish between them.
- (b) Define the terms transparent and opaque.
- (c) State the laws of reflection.
- (d) Draw the normal to a boundary and identify it in a given diagram.
- (e) Identify the angle of incidence and the angle of reflection.
- (f) Draw ray diagrams to show how light reflects by a plane boundary. The use of more than one reflecting surface placed in the path of the ray such as in periscopes can be examined.
- (g) Distinguish between real and virtual images.
- (h) Use geometric and trigonometric relations, together with the law of reflection to work out problems.

## 7.4.2 Refraction

Candidates should be able to:

- (a) Draw diagrams to show how the wavelength changes when the wave passes from one medium to another.
- (b) State the laws of refraction. This includes Snell's law.
- (c) Identify the angle of incidence and that of refraction.
- (d) Identify the angle of deviation and calculate it from the angle of incidence and that of refraction.

## 7.4.3 Refractive index

Candidates should be able to:

**Content****Learning outcomes and comments**

- (a) Define the refractive index of medium 2 with respect to medium 1 ( ${}_1n_2$ ) and the absolute refractive index of a medium ( $n_1$ ). Only questions involving positive refractive indices will be examined.
- (b) Give an estimate of the absolute refractive index for air.
- (c) State and use the equation  ${}_1n_2 = \frac{v_1}{v_2}$  where  $v_1$  is the speed in medium 1 and  $v_2$  is the speed in medium 2 to solve problems.
- (d) Discuss how the wavelength of monochromatic light depends on the medium.
- (e) Derive and use the equation  ${}_1n_2 = \frac{\lambda_1}{\lambda_2}$  where  $\lambda$  is the wavelength.
- (f) State and use the equation  $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ , where  $n_1$  and  $n_2$  are respectively the refractive indices of medium 1 and 2 while  $\theta_1$  and  $\theta_2$  are respectively the angles the rays make with the normal in medium 1 and medium 2.
- (g) Combine the laws of refraction and reflection with geometric and trigonometric relations to solve problems.
- (h) State the principle of reversibility and use it to justify the equation  ${}_1n_2 = \frac{1}{{}_2n_1}$ .
- (i) State and use the equation 
$$n = \frac{\text{Real depth}}{\text{Apparent depth}}$$

## 7.4.4 Total internal reflection

Candidates should be able to:

- (a) Use diagrams to illustrate what happens at a boundary between media to light rays originally travelling in the optically denser medium as the angle of incidence is increased from zero.
- (b) Define the critical angle.
- (c) State the conditions for total internal reflection.
- (d) Derive and use the equation  $\sin(c) = \frac{n_2}{n_1}$ , where  $c$  is the critical angle and  $n_1$  is the refractive index of the optically denser medium while  $n_2$  is that of the optically rarer medium.
- (e) Discuss how right angle prisms can be used to deflect light by  $90^\circ$ .
- (f) Name a naturally occurring phenomenon that depends on total internal reflection.
- (g) Discuss the application of total internal reflection in step-index fibres. The details of the input and the output of signals will not be examined.

## 7.4.5 Dispersion

Candidates should be able to:

**Content****Learning outcomes and comments**

- (a) Define dispersion.
- (b) State how the refractive index of a given medium depends on the wavelength/frequency of the incident light.
- (c) Draw diagrams indicating how light consisting of multiple wavelengths/frequencies is dispersed as it passes through a dispersive medium such as a prism.

## 7.4.6 Refraction of light by a single thin lens

Candidates should be able to:

- (a) Use ray diagrams to illustrate the following for both type of lenses: principal axis, principal focus, optical centre, focal plane and focal length.
- (b) Draw ray diagrams to show how an image is formed by a given single converging lens for different object distances.
- (c) Draw a ray diagram to show how an image is formed by a given single diverging lens.
- (d) Use either the real-is-positive or the Cartesian sign convention to solve problems.
- (e) State the lens equation and use it to solve problems involving a single thin converging or diverging lens.
- (f) Define linear magnification.
- (g) State and use the equations for magnification to solve problems involving a single thin converging or diverging lens.
- (h) Describe a rough method for determining the focal length of a thin converging lens.
- (i) Describe in detail an experiment to determine the focal length of a thin converging lens using a graphical method. This includes providing a diagram, the procedure, adequate precautions, the measurements made as well as the calculations.

## 7.5 The expansion of the universe

## 7.5.1 Doppler shift

Candidates should be able to:

- (a) Distinguish between stars, planets and galaxies.
- (b) Explain how Doppler shifts arise.
- (c) Distinguish between red and blue Doppler shifts.
- (d) Relate qualitatively the Doppler red and blue shifts with the relative velocity between the emitter and the observer.
- (e) Relate qualitatively the Doppler red and blue shifts with changes in wavelength and those in the absorption spectra.
- (f) State and use the relativistic Doppler equation

for low speeds  $f = f_0 \left( 1 - \frac{v}{c} \right)$ , where  $f$  is the

frequency measured by the observer,  $f_0$  is frequency emitted by the source,  $v$  is the velocity of the source relative to the observer and  $c$  is the speed of light. For this equation  $v$  is positive if the observer and the source are moving away from each other and negative if they are moving towards each other.

**Content****Learning outcomes and comments**

## 7.5.2 The cosmological red shift

Candidates should be able to:

- Explain how the cosmological red shift arises.
- State Hubble's law.
- State and use the equation  $v = Hd$  where  $v$  is the relative velocity,  $d$  is the distance and  $H$  is Hubble's constant.
- Define light year.
- Convert quantities measured in light year to the S.I. equivalent and convert back.

## 7.5.3 The Big Bang

Candidates should be able to:

- Explain the current model of the expansion of the universe. This can be done using analogies such as ribbons on an elastic band or dots on a balloon.
- Explain qualitatively what the Big Bang theory is. Details of the various stages (e.g. quark-lepton era, hadron era, etc.) will not be examined.
- List the Hubble's law, the cosmic background radiation, the abundance of isotopes and the observed distribution of the matter as supporting evidence the Big Bang theory.
- Explain why the cosmological red shift (Hubble's law) and the cosmic background radiation support the Big Bang theory.

## 7.5.4 The age of the universe

Candidates should be able to:

- Use Hubble's law and Hubble's constant to calculate an estimate age for the universe.
- Relate the uncertainty in the age of the universe to the uncertainties in the Hubble's constant and the measurement of astronomical distances.

## 8. Nuclear, atomic, quantum theory and particle physics

## 8.1 Nuclear Physics

## 8.1.1 Rutherford's alpha scattering experiment and nuclear size

Candidates should be able to:

- Describe in detail the alpha scattering experiment. This includes providing a basic diagram, procedure used, precautions taken and observations made.
- Discuss how the conclusions derived from the observations made in the alpha scattering experiment lead to a nuclear model of the atom.
- Derive and use an expression for the distance of closest approach and explain how this value yields an upper limit to the radius of the nucleus in question.
- Define nucleon.
- State and use the formula  $R = R_0 A^{1/3}$ , where  $R$  is the nuclear radius,  $R_0$  is the radius of a nucleon and  $A$  is the nucleon number.

## 8.1.2 The nucleus

Candidates should be able to:

**Content****Learning outcomes and comments**

- List the following properties of electrons, protons and neutrons: the approximate ratio of their masses relative to that of a nucleon and express their charges in terms of the electronic charge  $e$ .
- Define the terms: proton (or atomic) number  $Z$ , neutron number  $N$  and nucleon (or mass) number  $A$ .
- State and use the equation  $A = Z + N$ .
- Define element and isotope.
- Represent an element with given chemical symbol or using letter(s) together with the nucleon and proton number. These should be set in the general form  ${}^A_Z X$  where  $X$  is the symbol for the element.
- Identify the notation “isotope name”- $A$  as giving the isotope name together with the nucleon (mass) number.

## 8.1.3 The strong nuclear force

Candidates should be able to:

- Calculate the coulomb repulsive forces inside a nucleus given the necessary data.
- Explain the role of the strong nuclear force in keeping the nucleons together.
- Compare the magnitude and range of the strong nuclear force with those of the electrostatic force.

## 8.1.4 Elementary particles

Candidates should be able to:

- Distinguish between the two sets of elementary particles, namely quarks and leptons, in terms of the strong nuclear force.
- List the following leptons: electron, tau particle (tauon), muon, electron neutrino, tau neutrino and muon neutrino together with their corresponding antimatter particles.
- Identify  $\nu$  and  $\bar{\nu}$  as the symbols representing the neutrino and the antineutrino respectively.
- Explain what is meant by elementary and composite particles giving examples.
- Classify hadrons as composite particles made up of quarks and antiquarks.
- Classify protons and neutrons as hadrons.
- Compare the mass and charge (if any) of a particle with that of its corresponding anti-particle.
- Calculate the electric charge of hadrons given the fractional electric charge value of the constituent quarks.

## 8.1.5 Radioactive decay

Candidates should be able to:

- Define the terms radioactive decay, activity, decay constant and half-life.
- Identify  $\frac{dN}{dt}$ , where  $N$  is the number of radioactive nuclei in a sample and  $t$  is time, as the decay rate.
- Use the Becquerel as the unit of activity.
- State the law of radioactive decay.

**Content****Learning outcomes and comments**

- (e) State and use the equation  $\frac{dN}{dt} = -\lambda N$  or  $A = \lambda N$  where  $\lambda$  is the radioactive decay constant and  $A$  is the activity.
- (f) State and use the equation  $N = N_0 e^{-\lambda t}$ , where  $N_0$  is the number of nuclei in a sample when the time  $t = 0$  s and  $e$  is the base of natural logarithms.
- (g) Derive and use the equation  $T_{\frac{1}{2}} = \frac{\ln(2)}{\lambda}$  where  $T_{\frac{1}{2}}$  is the half-life.
- (h) Identify the sources of background radiation.
- (i) Describe in detail an experiment to determine the half-life of radon gas. This includes providing a diagram, the procedure, adequate precautions, measurements made and how the half-life is obtained by a graphical method.

## 8.1.6 Radioactive dating

Candidates should be able to:

- (a) Use the half-life to determine the age of a sample.
- (b) Explain that the uncertainty in the age of a sample depends on the randomness of radioactive decay.

## 8.1.7 Modes of radioactive decay

Candidates should be able to:

- (a) Sketch the stability curve on a neutron number against proton number graph and use it to distinguish between nuclei which are stable and those which are unstable to radioactive decay.
- (b) Explain what alpha ( $\alpha$ ) particles, beta particles (both  $\beta^+$  and  $\beta^-$ ) and gamma ( $\gamma$ ) radiation are and compare their physical properties.
- (c) Describe the alpha, beta (both  $\beta^+$  and  $\beta^-$ ) and gamma decay processes.
- (d) Write down nuclear equations to represent alpha and beta (both  $\beta^+$  and  $\beta^-$ ) decay.
- (e) Relate beta decay processes to the decay of the protons and the neutrons.
- (f) Describe the energy spectrum of the beta decay particles and use it to predict the existence of the neutrino and the antineutrino.
- (g) State and use the inverse square law for the intensity of gamma radiation.

## 8.1.8 Radiation absorption

Candidates should be able to:

- (a) Define the term half-value thickness.
- (b) State and use the equation  $I = I_0 e^{-\mu x}$ , where  $I$  is the intensity of radiation,  $I_0$  is the incident intensity of radiation,  $\mu$  is the absorption coefficient and  $x$  is the thickness of absorber.
- (c) Derive and use the equation  $x_{\frac{1}{2}} = \frac{\ln(2)}{\mu}$ , where  $x_{\frac{1}{2}}$  is the half-value thickness.

**Content****Learning outcomes and comments**

## 8.1.9 Nuclear energy

Candidates should be able to:

- Define the atomic mass unit.
- Convert a mass expressed in kilograms into atomic mass units and vice versa.
- Define the terms mass defect, binding energy and binding energy per nucleon.
- State and use the equation  $E = mc^2$ , where  $E$  is the energy,  $m$  is the mass and  $c$  is the speed of light.
- Convert between mass and energy using appropriate conversion factors.

## 8.1.10 Fission and fusion as sources of energy

Candidates should be able to:

- Sketch the binding energy per nucleon against nucleon number curve.
- Explain the terms nuclear fusion and nuclear fission.
- Use the binding energy per nucleon against nucleon number curve to predict which nuclear reactions will result in release of energy.
- Write down nuclear equations representing fission and fusion reactions given sufficient information.
- Describe the fission of uranium and the concept of chain reaction.
- Discuss the pros and cons of using nuclear energy with particular reference to carbon free energy.
- Calculate the energy released during given fusion and fission reactions.

## 8.2 Quantum theory

## 8.2.1 The Photoelectric effect

Candidates should be able to:

- Describe a simple demonstration of the photoelectric effect. The observations made should be included.
- State the properties of photoelectric emission and compare them with the predictions of the wave theory of light.
- Relate photons to electromagnetic waves.
- State and use the equation  $E = hf$ , where  $E$  is the photon energy,  $h$  is Planck's constant and  $f$  is the frequency.
- State Einstein's photoelectric equation and apply it in solving problems.
- Discuss how Einstein's photoelectric equation can be used to explain the experimental observations of the photoelectric effect.
- Describe the photocell experiment involving stopping potentials to verify Einstein's photoelectric equation. This includes providing a circuit diagram, the procedure, adequate precautions, measurements made, how Einstein's equation is verified graphically and the determination of Planck's constant.

## 8.2.2 Atomic energy levels

Candidates should be able to:

**Content****Learning outcomes and comments**

- Explain that an accelerating electron emits electromagnetic waves making Rutherford atomic model unstable.
- Describe how emission and absorption line spectra of isolated atoms can be produced. Hence infer that atoms have discrete energy levels.
- Sketch suitable energy level diagrams for atoms from a given set of data.
- Define ground state, excited state, ionization and ionization energy.
- Explain why the energy levels are assigned a negative energy value.
- State the conditions for an electron to transition between the energy levels of an atom.
- State and use the equation  $\Delta E = hf$ , where  $\Delta E$  is the change in energy (or the difference between energy levels).

## 8.2.3 Wave properties of the matter

Candidates should be able to:

- Describe qualitatively how matter particles such as electrons can exhibit wave-like behaviour, such as diffraction and interference, under certain conditions.
- Describe qualitatively an experiment involving diffraction of electrons by a crystal and explain how this can be used to verify the wave nature of electrons. This includes linking the pattern observed to probability of finding an electron.
- Discuss how an orbiting electron in an atom can be represented by standing waves.
- State how the standing wave representation of electrons in an atom is linked to the probability of finding an electron at a specific position.
- State and use the de Broglie equation,  $\lambda = \frac{h}{p}$ , where  $\lambda$  is the associated (de Broglie) wavelength and  $p$  the momentum.

## 9. Data analysis and experimental physics

## 9.1 Graphs

Candidates should be able to:

- Sketch and identify plots corresponding to simple equations including the following:
 
$$y = kx + c, \quad y = kx, \quad y = kx^2, \quad y = \frac{k}{x},$$

$$y = \frac{k}{x^2}, \quad y = \sin(kx), \quad y = \cos(kx), \quad y = e^{kx}$$
 and  $y = e^{-kx}$ . Here  $x$  and  $y$  are general variables while  $k$  and  $c$  are constants.
- Identify the rate of change of  $y$  with respect to  $x$  as the gradient of the tangent to a curve and use  $\frac{dy}{dx}$  to represent it. The use of calculus will not be examined.
- Use the scale of the axes to determine the coordinates of a point on a curve.

**Content****Learning outcomes and comments**

- (d) Determine the gradient at a point on a curve.
- (e) Determine or estimate the area between a curve and an axis. Use of calculus will not be examined.
- (f) Identify the area between a curve and an axis with a physical quantity when this has physical significance.

## 9.2 Data manipulation and plotting of graphs

Candidates should be able to:

- (a) Translate information between numerical data, algebraic equations, word statements and graphical representations.
- (b) Round off calculated values to an appropriate number of significant figures that will depend on the precision of the given data or direct measurements.
- (c) Select and plot two variables from experimental or other data, choosing suitable scales and range. This means that the graph needs not start from the origin.
- (d) Use the range and the number of boxes to determine a convenient scale. The scale should be easy to use, such as 1, 2 and 5. In addition the plotted points should be spread over more than half the range of each axis.
- (e) Use scale factors of the form  $10^n$  where  $n$  is an integer and/or SI prefixes to simplify the scale of an axis.
- (f) Label the axis of a graph using the appropriate notation. The appropriate notation is of the form  $V / 10^{-3} \text{ V}$ ,  $V / \text{mV}$  or Voltage / millivolts. The forms  $V (\text{V})$  and  $V / \times 10^{-3} \text{ V}$  will not be accepted. In the case of logarithms the appropriate notation is of the form  $\ln(V / \text{V})$ .
- (g) Draw the line or curve that best fits the plotted set of data points. The sum of the vertical distances of the data points above the line should be equal to that of the data points below the line. In addition the vertical distances should be minimal.

## 9.3 Straight line graphs and data analysis

Candidates should be able to:

- (a) Distinguish between linear and proportional relations.
- (b) Derive an equation for a relation between variable terms which are proportional by adding the appropriate constant of proportionality and vice versa.
- (c) Explain why straight lines are generally preferred when analysing data.
- (d) Determine the gradient of a straight line graph.
- (e) Determine the  $y$ -intercept of a straight line from the point of intersection with the line  $x = 0$  and by using the straight line equation together with two points on the straight line.
- (f) Set a given equation in a straight line format identifying the  $x$  and  $y$  variables as well as the gradient and the intercept. This includes the

<b>Content</b>	<b>Learning outcomes and comments</b>
	use of logarithms (both to base 10 and to base $e$ ).
9.4 Measurement techniques	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Choose and use appropriate instruments and techniques to measure mass, length, time, current, voltage, resistance and temperature. The instruments can be both analogue and digital.</li> <li>(b) Take measurements using micrometer and vernier scales.</li> </ul>
9.5 Systematic and random errors	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Distinguish between systematic and random errors giving examples of each.</li> <li>(b) Explain how repeated measurements are used to reduce the effect of random errors.</li> <li>(c) Identify errors in a given experiment.</li> <li>(d) Devise precautions to minimize the effects of (systematic and random) errors.</li> </ul>
9.6 Uncertainties in measured quantities	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Use the least count of an instrument as the estimate of the uncertainty in direct measurements. This will not apply to a stopwatch where the student should not quote the uncertainty because the reaction error is generally larger than the least count. However, measurements made with a stopwatch should be rounded to 0.1 s. Furthermore, the candidates are not expected to quote the uncertainty in calculated values.</li> <li>(b) Round the measured values to the same decimal place as their respective estimated uncertainty.</li> <li>(c) Tabulate values consistently using the appropriate notation for the headings.</li> </ul>
9.7 Experimental design and data handling	<p>Candidates should be able to:</p> <ul style="list-style-type: none"> <li>(a) Follow a given set of instructions to carry out an experiment using given apparatus.</li> <li>(b) Assemble simple electric circuits using given circuit diagrams.</li> <li>(c) Connect and use a multimeter in order to measure current, voltage and resistance, setting it to the appropriate scale.</li> <li>(d) Take repeated measurements wherever possible.</li> <li>(e) Unless otherwise stated, take a minimum of five different sets of measurements in order to plot a straight line graph.</li> <li>(f) Select appropriate values within a given range when measuring an independent variable.</li> <li>(g) Tabulate measurements and calculated values as appropriate.</li> </ul>

**General note**

The candidate should be able to identify analogies of physical phenomena across the syllabus.

### **Addendum**

At a meeting of the General Conference on Weights and Measures, the body responsible for the definition of the SI units, a new definition of the **Ampere and the mole** was adopted. The change came into effect on the 20<sup>th</sup> of May 2019.

In view of this, an interim period has been set during which both the old and the new version will be accepted. This period will end in September 2021.

To facilitate the transition, the following statements are being provided as references for the candidates,

*The ampere is defined in terms of the fixed numerical value of the elementary charge  $e$  when expressed in coulombs, where the unit of coulomb is equal to ampere second.*

*One mole contains the same number of elementary entities as the Avogadro constant.*

until such time when standard textbooks with the new definitions are available.