A Physics Cambridge Survival Guide

This Survival Guide Belongs To:

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Intro to Cambridge Physics

Welcome to A Physics! One of our primary goals is to prepare you for the Cambridge test at the end of the year. Part of your A level test grade will be based on how you scored on the AS level test. Papers 1-3 were taken on for the AS Test.

Parts of the Cambridge Physics Test:

1. *Paper 4: Structured Questions (2 hours)*
   This paper consists of a variable number of questions of variable mark value. All questions will be based on the A Level syllabus but may require knowledge of material first encountered in the AS Level syllabus. Candidates will answer all questions. This paper will test assessment objectives AO1 (48%) & AO2 (52%).
2. *Paper 5: Planning, Analysis and Evaluation (1 hour 15 minutes)*
   This paper consists of two questions of equal mark value based on the practical skills of planning, analysis and evaluation. The context of the questions may be outside the syllabus content, but candidates will be assessed on their practical skills of planning, analysis and evaluation rather than their knowledge of theory. Candidates will answer both questions. This paper will test assessment objectives AO3.

Notice that each paper says which assessment objectives are tested on that paper. For more information, see the "Assessment Objectives" page.

	A Level
Paper 1	15.5%
Paper 2	23%
Paper 3	11.5%
Paper 4	38.5%
Paper 5	11.5%

Number Notation:
Numbers from 1000 to 9999 will be printed without commas or spaces. Numbers greater than or equal to 10 000 will be printed without commas. A space will be left between each group of three whole numbers, e.g. 4 256 789.

Significant Figures:
Cambridge is very particular about using the correct number of significant figures. If a correct number answer is not written with the appropriate number of significant figures, you may not receive a mark (or point) for your answer. You need to be able to take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified.

Except where they are produced by addition or subtraction, calculated quantities should be given to the same number of significant figures (or one more than) the measured quantity of least accuracy. For example, if values of a potential difference and of a current are measured to 2 and 4 significant figures respectively, then the corresponding resistance should be given to 2 or 3 significant figures, but not 1 or 4. The number of significant figures may, if necessary, vary down a column of values for a calculated quantity.

Mathematical Requirements

Calculators may be used in all parts of the examination. Note that when Cambridge says "recall" they mean you need to have that memorized and that you can recall that fact at the test. That information will not be given. **For the information below, the bolded information is the new content required on the A Physics test.**

Arithmetic: Candidates should be able to...

- recognise and use expressions in decimal and standard form (scientific) notation
- **recognise and use binary notation**
- use an electronic calculator for addition, subtraction, multiplication and division. Find arithmetic means, powers (including reciprocals and square roots), sines, cosines, tangents (and the inverse functions), **exponentials and logarithms (lg and ln)**
- take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified
- make approximate evaluations of numerical expressions (e.g. $\pi^2 \approx 10$) and use such approximations to check the magnitude of calculated results.

Algebra: Candidates should be able to...

- change the subject of an equation. Most relevant equations involve only the simpler operations but may include positive and negative indices and square roots.
- solve simple algebraic equations. Most relevant equations are linear but some may involve inverse and inverse square relationships. Linear simultaneous equations and the use of the formula to obtain the solutions of quadratic equations are required.
- substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations
- set up simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models
- **recognise and use the logarithms of expressions like ab, a/b, x^n, e^{kx} and understand the use of logarithms in relation to quantities with values that range over several orders of magnitude**
- express small changes or uncertainties as percentages and vice versa
- understand and use the symbols <, >, <, >, %, &, ≈, /, ∝, Σ, Δx, √

Geometry and Trigonometry: Candidates should be able to...

- calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of cuboids, cylinders and spheres
- use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle
- use sines, cosines and tangents of angles (especially for 0°, 30°, 45°, 60°, 90°)
- use the trigonometric relationships for triangles:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} \qquad a^2 = b^2 + c^2 - 2bc\cos A$$

- $\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small θ; $\sin 2\theta + \cos^2\theta = 1$
- understand the relationship between degrees and radians, convert from one to the other and use the appropriate system in context

Vectors: Candidates should be able to...

- find the resultant of two coplanar vectors, recognising situations where vector addition is appropriate
- obtain expressions for components of a vector in perpendicular directions, recognising situations where vector resolution is appropriate.

Graphs: Candidates should be able to...

- translate information between graphical, numerical, algebraic and verbal forms
- select appropriate variables and scales for graph plotting
- determine the gradient, intercept and intersection of linear graphs
- choose, by inspection, a straight line which will serve as the line of best fit through a set of data points presented graphically
- draw a curved trend line through a set of data points presented graphically, when the arrangement of these data points is clearly indicative of a non-linear relationship
- recall standard linear form y= mx+ cand rearrange relationships into linear form where
- appropriate
- sketch and recognise the forms of plots of common simple expressions like
- $1/x$, x^2, $1/x^2$, sin x, cos x, $\mathbf{e^{-x}}$
- **use logarithmic plots to test exponential and power law variations**
- draw a tangent to a curve, and understand and use the gradient of the tangent as a means to obtain the gradient of the curve at a point
- understand and use the area below a curve where the area has physical significance.

Assessment Objectives

AO1: Knowledge with understanding

Candidates should be able to demonstrate knowledge and understanding of:

1. scientific phenomena, facts, laws, definitions, concepts and theories
3. scientific vocabulary, terminology and conventions (including symbols, quantities and units)
4. scientific instruments and apparatus, including techniques of operation and aspects of safety
5. scientific quantities and their determination
6. scientific and technological applications with their social, economic and environmental implications.

The syllabus content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these assessment objectives will often begin with one of the following words: define, state, describe, or explain (see Glossary of Terms section).

AO2: Handling information and problem solving

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to locate, select, organise and present information from a variety of sources

1. translate information from one form to another
2. manipulate numerical and other data
3. use information to identify patterns, report trends, draw inferences and report conclusions
4. present reasoned explanations for phenomena, patterns and relationships
5. make predictions and put forward hypotheses
6. apply knowledge, including principles, to new situations
7. evaluate information and hypotheses
8. demonstrate an awareness of the limitations of physical theories and models.

These assessment objectives cannot be precisely specified in the syllabus content because questions testing such skills may be based on information that is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a new situation. Questions testing these objectives will often begin with one of the following words: predict, suggest, deduce, calculate or determine (see Glossary of Terms section).

AO3: Experimental skills and investigations

Candidates should be able to:

1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements

This Assessment objective will only be tested in Paper 3.

Glossary of Terms

This glossary should prove helpful to candidates as a guide, although it is not exhaustive and it has deliberately been kept brief. Candidates should understand that the meaning of a term must depend in part on its context. The number of marks allocated for any part of a question is a guide to the depth required for the answer.

1. *Define* (the term(s)...) is intended literally. Only a formal statement or equivalent paraphrase, such as the defining equation with symbols identified, is required.
2. *What is meant by*... normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The number of marks indicated will suggest the amount of supplementary comment required.
3. *Explain* may imply reasoning or some reference to theory, depending on the context.
4. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.
5. *List* requires a number of points with no elaboration. If a specific number of points is requested, this number should not be exceeded.
6. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. For particular phenomena, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. The amount of description intended is suggested by the indicated mark value.
7. *Discuss* requires candidates to give a critical account of the points involved in the topic.
8. *Deduce/Predict* implies that candidates are not expected to produce the required answer by recall, but by making a logical connection between other pieces of information. Such information may be wholly given in the question, or may depend on answers extracted in an earlier part of the question.
9. *Suggest* is used in two main contexts. It may imply either that there is no unique answer or that candidates are expected to apply their general knowledge to a new situation (one that may not, formally, be in the syllabus).
10. *Calculate* is used when a numerical answer is required. In general, working should be shown.
11. *Measure* mplies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.
12. *Determine* often implies that the quantity concerned cannot be measured directly, but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. the Young modulus, relative molecular mass.
13. *Show* is used where a candidate is expected to derive a given result. It is important that the terms being used by candidates are stated explicitly and that all stages in the derivation are stated clearly.
14. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned. Candidates should make any necessary simplifying assumptions about points of principle and about the values of quantities not otherwise included in the question.
15. *Sketch*(applied to graph work) implies that the shape and/or position of the curve need only be qualitatively correct. However, candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value. On a sketch graph it is essential that candidates clearly indicate what is being plotted on each axis.
16. *Sketch*(applied to diagrams) implies that a simple, freehand drawing is acceptable, though care should be taken over proportions and the clear exposition of important details.
17. *Compare* requires candidates to provide both similarities and differences between things or concepts.

Paper 5

Paper 5 will be a timetabled written paper, focusing on the following higher-order experimental skills:

- planning
- analysis, conclusions and evaluation.

This examination will not require laboratory facilities.

Paper 5 will consist of two questions each of 15 marks.

The first question will be a planning question, in which candidates will be required to design an experimental investigation of a given problem. The question will not be highly structured: candidates will be expected to answer with a diagram and an extended piece of writing.

The second question will be an analysis, conclusions and evaluation question, in which candidates will be given an equation and some experimental data. From these they will be required to find the value of a constant. This question will be structured but candidates will be expected to decide for themselves what they need to do in order to reach an answer. They will also be required to estimate the uncertainty in their answer.

Some questions on this paper may be set in areas of physics that are difficult to investigate experimentally in school laboratories, either because of the cost of equipment or because of restrictions on the availability of materials (e.g. radioactive materials). No question will require knowledge of theory or equipment that is beyond the syllabus: candidates will be given all the information that they need. Candidates will be given the necessary information for questions set on topics that do not form part of the syllabus.

Mark scheme for Paper 5

Paper 5 will be marked using the generic mark scheme below. The expectations for each mark category are listed in the sections that follow.

Question 1			
Skill	**Mark allocation**	**Breakdown of skills**	**Mark allocation**
Planning	15 marks	Defining the problem	2 marks
		Methods of data collection	4 marks
		Method of analysis	3 marks
		Additional detail including safety considerations*	6 marks

*The 6 marks for additional detail will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Question 2			
Skill	**Mark allocation**	**Breakdown of skills**	**Minimum mark allocation***
Analysis, conclusions and evaluation	15 marks	Data analysis	1 mark
		Table of results	1 mark
		Graph	2 marks
		Conclusion	3 marks
		Treatment of uncertainties	3 marks

*The remaining 5 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Expectations for Each Mark Category

Planning

Defining the problem

Candidates should be able to:

- identify the independent variable in the experiment
- identify the dependent variable in the experiment
- identify the variables that are to be kept constant.

Methods of data collection

Candidates should be able to:

- describe the method to be used to vary the independent variable
- describe how the independent and dependent variables are to be measured
- describe how other variables are to be kept constant
- describe, with the aid of a clear labelled diagram, the arrangement of apparatus for the experiment and the procedures to be followed.

For full credit to be awarded in this section, the overall arrangement must be workable, that is, it should be possible to collect the data required without undue difficulty if the apparatus were assembled as described. The measuring instruments chosen should be fit for purpose, in that they should measure the correct physical quantity to a suitable precision for the experiment.

Method of analysis

Up to six marks will be available for additional relevant detail including safety precautions.

Additional detail including safety considerations

Up to six marks will be available for additional relevant detail including safety precautions.

How these marks are awarded will depend on the experiment that is to be planned, but they might, for example, include marks for describing how additional variables are to be kept constant, or for a diagram of a circuit needed to make a particular measurement or a description of initial experiments or an explanation of how to obtain calibration curves.

For safety considerations, candidates should be able to:

- assess the risks of their experiment
- describe precautions that should be taken to keep risks to a minimum.

Marks may also be awarded for detailed use of apparatus.

Candidates should be able to:

- describe the use of an oscilloscope (or storage oscilloscope) to measure voltage, current, time and frequency
- describe how to use light gates connected to a data logger to determine time, velocity and acceleration
- describe how other sensors can be used with a data logger, e.g. motion sensor.

Analysis, conclusions and evaluation

Data analysis

Candidates should be able to:

- rearrange expressions into the forms $y= mx+ c$, $y= ax^n$ and $y= ae^{kx}$
- plot a graph of y against x and use the graph to find the constants mand cin an equation of the form $y= mx+ c$
- plot a graph of log y against log x and use the graph to find the constants aand nin an equation of the form $y= ax^n$
- plot a graph of ln y against x and use the graph to find the constants aand kin an equation of the form $y= ae^{kx}$
- decide what derived quantities to calculate from raw data in order to enable an appropriate graph to be plotted
- calculate other quantities from their raw data
- use the correct number of significant figures for these calculated quantities following the conventions required for Paper 3

Where logarithms are required, units should be shown with the quantity whose logarithm is being taken, e.g. ln (d/ cm). The logarithm itself does not have a unit.

For logarithmic quantities, the number of decimal places should correspond to the number of significant figures. For example, if L/ cm is 76.5 (3 sf), then lg (L/ cm) should be either 1.884 (3 dp) or 1.8837 (4 dp).

Table of results

Candidates should be able to:

- complete a table of results following the conventions required for Paper 3.

Graph

Candidates should be able to:

- plot a graph following the conventions required for Paper 3
- show error bars, in both directions where appropriate, for each point on the graph
- draw a straight line of best fit and a straight worst acceptable line through the points on the graph when the trend on the graph is linear
- draw a curved trend line and a tangent to the curve where appropriate.

The worst acceptable line should be either the steepest possible line or the shallowest possible line that passes through the error bars of all the data points. It should be distinguished from the line of best fit either by being drawn as a broken line or by being clearly labelled.

Conclusion

Candidates should be able to:

- determine the gradient and y-intercept of a straight-line graph or tangent to a curve
- derive expressions that equate to the gradient or the y-intercept of their straight lines of best fit
- draw the required conclusions from these expressions.

Treatment of uncertainties

Candidates should be able to:

- determine the gradient and y-intercept of a straight-line graph or tangent to a curve
- convert absolute uncertainty estimates into fractional or percentage uncertainty estimates and vice versa
- show uncertainty estimates, in absolute terms, beside every value in a table of results
- calculate uncertainty estimates in derived quantities
- show uncertainty estimates as error bars on a graph
- estimate the absolute uncertainty in the gradient of a graph by recalling that absolute uncertainty = gradient of line of best fit – gradient of worst acceptable line
- estimate the absolute uncertainty in the y-intercept of a graph by recalling that absolute uncertainty = y-intercept of line of best fit – y-intercept of worst acceptable line
- express a quantity as a value, an uncertainty estimate and a unit.

Apparatus That is Used Regularly

Below is a list of the items that are regularly used in Paper 3. The list is not exhaustive: other items are usually required, to allow for variety in the questions set.

- Cells: 1.5 V
- Connecting leads and crocodile clips
- Digital ammeter, minimum ranges 0–1 A reading to 0.01 A or better, 0–200 mA reading to 0.1 mA or better, 0–20 mA reading to 0.01 mA or better (digital multimeters are suitable)
- Digital voltmeter, minimum ranges 0–2 V reading to 0.001 V or better, 0–20 V reading to 0.01 V or better (digital multimeters are suitable)
- Lamp and holder: 6 V 60 mA; 2.5 V 0.3 A
- Power supply: variable up to 12 V d.c. (low resistance)
- Rheostat (with a maximum resistance of at least 8 Ω, capable of carrying a current of at least 4 A)
- Switch
- Wire: constantan 26, 28, 30, 32, 34, 36, 38 s.w.g. or similar metric sizes
- Long stem thermometer: –10 °C to 110 °C ×1 °C
- Means to heat water safely to boiling (e.g. an electric kettle)
- Plastic or polystyrene cup 200 cm^3
- Stirrer
- Adhesive putty (e.g. Blu-Tack)
- Adhesive tape (e.g. Sellotape)
- Balance to 0.1 g (this item may often be shared between sets of apparatus)
- Bar magnet
- Bare copper wire: 18, 20, 26 s.w.g. or similar metric sizes
- Beaker: 100 cm^3, 200 cm^3, or 250 cm^3
- Card
- Expendable steel spring (spring constant approx. 25 N m^{-1}; unstretched length approx. 2 cm)
- G-clamp
- Magnadur ceramic magnets
- Mass hanger
- Micrometer screw gauge (this item may often be shared between sets of apparatus)
- Modelling clay (e.g. Plasticine)
- Newton-meter (1 N, 10 N)
- Pendulum bob
- Protractor
- Pulley
- Rule with a millimetre scale (1 m, 0.5 m, 300 mm)
- Scissors
- Slotted masses (100 g, 50 g, 20 g, 10 g) or alternative
- Stand, boss and clamp
- Stopwatch (candidates may use their wristwatches), reading to 0.1 s or better
- Stout pin or round nail
- String/thread/twine
- Vernier or digital calipers (this item may often be shared between sets of apparatus)
- Wire cutters

Structure of the Syllabus

The table shows which parts of the syllabus contain AS Level material and which contain additional material that is examined only in the full A Level.

Topic	AS Level	A Level
1 Physical quantities and units	✓	✓
2 Measurement techniques	✓	✓
3 Kinematics	✓	
4 Dynamics	✓	
5 Forces, density and pressure	✓	
6 Work, energy and power	✓	
7 Motion in a circle		✓
8 Gravitational fields		✓
9 Deformation of solids	✓	
10 Ideal gases		✓
11 Temperature		✓
12 Thermal properties of materials		✓
13 Oscillations		✓
14 Waves	✓	✓
15 Superposition	✓	
16 Communication		✓
17 Electric fields	✓	✓
18 Capacitance		✓
19 Current of electricity	✓	✓
20 D.C. circuits	✓	✓
21 Electronics		✓
22 Magnetic fields		✓
23 Electromagnetic induction		✓
24 Alternating currents		✓
25 Quantum physics		✓
26 Particle and nuclear physics	✓	✓

Syllabus Objectives

For the information below, the bolded information is the new content required on the A Physics test.

Physical quantities and units

The measurement and recording of quantities is central to the whole of physics. The skills of estimating a physical quantity and having a feeling for which quantities are reasonable and which are unreasonable are very useful for any physicist.

This topic introduces the SI system of units, which provides a universal framework of measurement that is common to all scientists internationally.

Candidates should be aware of the nature of a physical measurement, in terms of a magnitude and a unit. They should have experience of making and recording measurements in the laboratory.

1) Physical Quantities
   a) understand that all physical quantities consist of a numerical magnitude and a unit
   b) make reasonable estimates of physical quantities included within the syllabus
2) SI Units
   a) recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K)
   b) express derived units as products or quotients of the SIbase units and use the named units listed in this syllabus as appropriate
   c) use SIbase units to check the homogeneity of physical equations
   d) use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega(M), giga(G), tera(T)
   e) understand and use the conventions for labelling graph axes and table columns
3) **The Avagadro constant**
   a) **understand that the Avogadro constant N_A is the number of atoms in 0.012 kg of carbon-12**
   b) **use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant N_A**
4) Scalars and vectors
   a) distinguish between scalar and vector quantities and give examples of each
   b) add and subtract coplanar vectors
   c) represent a vector as two perpendicular components

Measurement techniques

Measurement is essential to the study of physics. Physicists need to be familiar with a wide range of measuring instruments.

Measurements themselves may be misleading and result in inappropriate conclusions as a result of errors and uncertainties. This topic develops an understanding of errors and uncertainties in measured and derived physical quantities.

1) Measurements
   a) use techniques for the measurement of length, volume, angle, mass, time, temperature and electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus. In particular, candidates should be able to:
      i) measure lengths using rulers, calipers and micrometers
      ii) measure weight and hence mass using balances
      iii) measure an angle using a protractor
      iv) measure time intervals using clocks, stopwatches and the calibrated
      v) time-base of a cathode-ray oscilloscope (c.r.o.)
      vi) measure temperature using a thermometer
      vii) use ammeters and voltmeters with appropriate scales
      viii) use a galvanometer in null methods
      ix) use a cathode-ray oscilloscope (c.r.o.)
      x) **use a calibrated Hall probe**

b) use both analogue scales and digital displays
c) use calibration curves

2) Errors and Uncertainties
a) understand and explain the effects of systematic errors (including zero errors) and random errors in measurements
b) understand the distinction between precision and accuracy
c) assess the uncertainty in a derived quantity by simple addition of absolute, fractional or percentage uncertainties (a rigorous statistical treatment is not required)

Kinematics

Kinematics is the study of motion. Movement is part of everyday experience, so it is important to be able to analyse and predict the way in which objects move.

The behaviour of moving objects is studied both graphically and through equations of motion.

1) Equations of Motion
a) define and use distance, displacement, speed, velocity and acceleration
b) use graphical methods to represent distance, displacement, speed, velocity and acceleration
c) determine displacement from the area under a velocity-time graph
d) determine velocity using the gradient of a displacement-time graph
e) determine acceleration using the gradient of a velocity-time graph
f) derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line
g) solve problems using equations that represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance
h) describe an experiment to determine the acceleration of free fall using a falling body
i) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction

Dynamics

The motion of any object is governed by forces that act on the object.

This topic introduces Newton's laws of motion, which are fundamental to understanding the connection between forces and motion. The concept of momentum and the use of momentum conservation to analyse interactions are also studied.

1) Momentum and Newton's Laws of Motion
a) understand that mass is the property of a body that resists change in motion
b) recall the relationship F= ma and solve problems using it, appreciating that acceleration and resultant force are always in the same direction
c) define and use linear momentum as the product of mass and velocity
d) define and use force as rate of change of momentum
e) state and apply each of Newton's laws of motion

2) Non-uniform Motion
a) describe and use the concept of weight as the effect of a gravitational field on a mass and recall that the weight of a body is equal to the product of its mass and the acceleration of free fall
b) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance

3) Linear momentum and its conservation
a) state the principle of conservation of momentum
b) apply the principle of conservation of momentum to solve simple problems, including elastic and inelastic interactions between bodies in both one and two dimensions (knowledge of the concept of coefficient of restitution is not required)
c) recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation
d) understand that, while momentum of a system is always conserved in interactions between bodies, some change in kinetic energy may take place

Forces, density and pressure

In this topic, the natures of some different types of force are studied, including how forces give rise to both translational and rotational equilibrium.

The concept of pressure is introduced. This acts as a starting point for later work on pressure in gases.

1) Types of forces
   a) describe the force on a mass in a uniform gravitational field and on a charge in a uniform electric field
   b) understand the origin of the upthrust acting on a body in a fluid
   c) show a qualitative understanding of frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required)
   d) understand that the weight of a body may be taken as acting at a single point known as its centre of gravity
2) Turning effects of forces
   a) define and apply the moment of a force
   b) understand that a couple is a pair of forces that tends to produce rotation only
   c) define and apply the torque of a couple
3) Equilibrium of forces
   a) state and apply the principle of moments
   b) understand that, when there is no resultant force and no resultant torque, a system is in equilibrium
   c) use a vector triangle to represent coplanar forces in equilibrium
4) Density and pressure
   a) define and use density
   b) define and use pressure
   c) derive, from the definitions of pressure and density, the equation $\Delta p= \rho g\Delta h$
   d) use the equation $\Delta p= \rho g\Delta h$

Work, energy and power

This topic introduces different forms of energy in both qualitative and quantitative terms. The concept of energy and its conservation provide useful accounting tools that help to understand the behaviour of physical systems.

The concepts of power and efficiency are also studied.

1) Energy conversion and conservation
   a) give examples of energy in different forms, its conversion and conservation, and apply the principle of conservation of energy to simple examples
2) Work and efficiency
   a) understand the concept of work in terms of the product of a force and displacement in the direction of the force
   b) calculate the work done in a number of situations including the work done by a gas that is expanding against a constant external pressure: $W= p\Delta V$
   c) recall and understand that the efficiency of a system is the ratio of useful energy output from the system to the total energy input
   d) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems
3) Potential energy and kinetic energy
   a) derive, from the equations of motion, the formula for kinetic energy $E_k = 1/2\ mv^2$
   b) recall and apply the formula $E_k = 1/2\ mv^2$
   c) distinguish between gravitational potential energy and elastic potential energy
   d) understand and use the relationship between force and potential energy in a uniform field to solve problems
   e) derive, from the defining equation $W= Fs$, the formula $\Delta E_p= mg\Delta h$ for potential energy changes near the Earth's surface
   f) recall and use the formula $\Delta E_p= mg\Delta h$ for potential energy changes near the Earth's surface
4) Power
   a) define power as work done per unit time and derive power as the product of force and velocity
   b) solve problems using the relationships $P = W/t$ and $P = Fv$

Motion in a circle

The turning effect of forces is introduced in Topic 5. In this topic, rotational motion, confined to motion in a circle, is studied.

Radian measure is introduced and equations for circular motion are developed, in terms of both angular and linear speeds.

1) **Kinematics of uniform circular motion**
   a) **define the radian and express angular displacement in radians**
   b) **understand and use the concept of angular speed to solve problems**
   c) **recall and use v= rω to solve problems**
2) **Centripetal acceleration and centripetal force**
   a) **describe qualitatively motion in a curved path due to a perpendicular force, and understand the centripetal acceleration in the case of uniform motion in a circle**
   b) **recall and use centripetal acceleration equations $a= r\omega^2$ and $a= v^2/r$**
   c) **recall and use centripetal force equations $F= mr\omega^2$ and Fmv^2/r**

Gravitational fields

Forces due to gravity are a familiar experience. These experiences are formalised in an understanding of the concept of a gravitational field and in Newton's law of gravitation.

Gravitational forces, along with gravitational potential, enable a study to be made of the circular orbits of planets and satellites.

1) **Gravitational field**
   a) **understand the concept of a gravitational field as an example of a field of force and define gravitational field strength as force per unit mass**
2) **Gravitational force between point masses**
   a) **understand that, for a point outside a uniform sphere, the mass of the sphere may be considered to be a point mass at its centre**
   b) **recall and use Newton's law of gravitation in the form $F = \frac{Gm_1m_2}{r^2}$**
   c) **analyse circular orbits in inverse square law fields, including geostationary orbits, by relating the gravitational force to the centripetal acceleration it causes**
3) **Gravitational field of a point mass**
   a) **derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \frac{GM}{r^2}$for the gravitational field strength of a point mass**
   b) **recall and solve problems using the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass**
   c) **show an appreciation that on the surface of the Earth g is approximately constant**
4) **Gravitational potential**
   a) **define potential at a point as the work done per unit mass in bringing a small test mass from infinity to the point**
   b) **solve problems using the equation $\varphi = -\frac{GM}{r}$ for the potential in the field of a point mass**

Deformation of solids

Solids change their shape under the action of forces. This change may be large in the case of springs or hardly noticeable in some structures such as buildings.

The study of the deformation of solids is an important aspect of engineering. This topic provides an introduction to both elastic and plastic deformation of materials.

2) Stress and strain
   a) appreciate that deformation is caused by a force and that, in one dimension, the deformation can be tensile or compressive
   b) describe the behaviour of springs in terms of load, extension, elastic limit, Hooke's law and the spring constant (i.e. force per unit extension)

   c) define and use the terms stress, strain and the Young modulus
   d) describe an experiment to determine the Young modulus of a metal in the form of a wire
3) Elastic and plastic behavior
   a) distinguish between elastic and plastic deformation of a material
   b) understand that the area under the force-extension graph represents the work done
   c) deduce the strain energy in a deformed material from the area under the force-extension graph

Ideal Gases

Real gases have complex behaviour, but it is possible to make progress in understanding gases by developing a simplified model of a gas called an ideal gas.

A link between the behaviour of gas molecules and temperature can be established. This provides an introduction to the concept of thermodynamic temperature.

1) Equation of state
   a) recall and solve problems using the equation of state for an ideal gas expressed as $pV = nRT$, where n= amount of substance (number of moles)
2) Kinetic theory of gases
   a) infer from a Brownian motion experiment the evidence for the movement of molecules
   b) state the basic assumptions of the kinetic theory of gases
   c) explain how molecular movement causes the pressure exerted by a gas and hence deduce the relationship $pV = 1/3\ Nm<c^2>$, where N= number of molecules
   d) [A simple model considering one-dimensional collisions and then
   e) extending to three dimensions using $1/3<c^2>=<c_x^2>$
3) Kinetic energy of a molecule
   a) recall that the Boltzmann constant k is given by the expression $k = R/N_A$
   b) compare $pV = 1/3Nm<c^2>$ with $pV = NkT$ and hence deduce that the average translational kinetic energy of a molecule is proportional to T

Temperature

A link between temperature and the behaviour of gas molecules was introduced in Topic 10. In this topic, the concept of temperature is explored in further detail.

Reference to two types of practical thermometer enable aspects of the measurement of temperature to be considered.

1) Thermal equilibrium
   a) appreciate that (thermal) energy is transferred from a region of higher temperature to a region of lower temperature
   b) understand that regions of equal temperature are in thermal equilibrium
2) Temperature scales
   a) understand that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties
   b) understand that there is an absolute scale of temperature that does not depend on the property of any particular substance (i.e. the thermodynamic scale and the concept of absolute zero)
   c) convert temperatures measured in kelvin to degrees Celsius and recall that $T/\text{K} = T/°\text{C} + 273.15$
3) Practical thermometers
   a) compare the relative advantages and disadvantages of thermistor and thermocouple thermometers as previously calibrated instruments

Thermal properties of materials

A simple kinetic model of matter is used to study properties of the three states of matter, including melting and vaporisation.

This topic then introduces the concept of internal energy and the first law of thermodynamics.

1) Specific heat capacity and specific latent heat
   a) explain using a simple kinetic model for matter:

- **the structure of solids, liquids and gases**
- **why melting and boiling take place without a change in temperature**
- **why the specific latent heat of vaporisation is higher than specific latent heat of fusion for the same substance**
- **why a cooling effect accompanies evaporation**

b) define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods
c) define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods

2) Internal energy and the first law of thermodynamics
a) understand that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system
b) relate a rise in temperature of a body to an increase in its internal energy
c) recall and use the first law of thermodynamics $\Delta U = q + w$ expressed in terms of the increase in internal energy, the heating of the system (energy transferred to the system by heating) and the work done on the system

Oscillations

Oscillations arise in many physical systems, and can be observed at both the microscopic and macroscopic level.

The study of oscillations is confined to simple harmonic motion. Equations that describe simple harmonic oscillations are developed in this topic.

Damping and resonance are introduced, and consideration given to situations where this can be either an advantage or a disadvantage.

1) Internal energy and the first law of thermodynamics
a) describe simple examples of free oscillations
b) investigate the motion of an oscillator using experimental and graphical methods
c) understand and use the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency
d) recognise and use the equation $a = -\omega^2 x$ as the defining equation of simple harmonic motion
e) recall and use $x = x_0 \sin \omega t$as a solution to the equation $a = -\omega^2 x$
f) recognise and use the equations $v = v_0 \cos \omega t$ and $v = \pm \omega \sqrt{x_0^2 - x^2}$
g) describe, with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion

2) Energy in simple harmonic motion
a) describe the interchange between kinetic and potential energy during simple harmonic motion

3) Damped and forced oscillations, resonance
a) describe practical examples of damped oscillations with particular reference to the effects of the degree of damping and the importance of critical damping
b) describe practical examples of forced oscillations and resonance
c) describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system, and understand qualitatively the factors that determine the frequency response and sharpness of the resonance
d) appreciate that there are some circumstances in which resonance is useful and other circumstances in which resonance should be avoided

Waves

This topic introduces the basic properties of transverse and longitudinal progressive waves, including the determination of the frequency and speed of sound waves. The electromagnetic spectrum is also introduced.

These basic properties of waves are developed further into a study of the Doppler effect and of ultrasound for diagnostic purposes.

The ideas of simple wave behaviour, such as reflection and refraction of light, would be useful prior knowledge.

1) Progressive waves
   a) describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks
   b) understand and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed
   c) deduce, from the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$
   d) recall and use the equation $v = f\lambda$
   e) understand that energy is transferred by a progressive wave
   f) recall and use the relationship intensity $\propto$ (amplitude)
2) Transverse and longitudinal waves
   a) compare transverse and longitudinal waves
   b) analyse and interpret graphical representations of transverse and longitudinal waves
3) Determination of frequency and wavelength in sound waves
   a) determine the frequency of sound using a calibrated cathode-ray oscilloscope (c.r.o.)
   b) determine the wavelength of sound using stationary waves
4) Doppler Effect
   a) understand that when a source of waves moves relative to a stationary observer, there is a change in observed frequency
   b) use the expression $f_0 = \frac{f_s v}{(v \pm v_s)}$ for the observed frequency when a source of sound waves moves relative to a stationary observer
   c) appreciate that Doppler shift is observed with all waves, including sound and light
5) Electromagnetic Spectrum
   a) state that all electromagnetic waves travel with the same speed in free space and recall the orders of magnitude of the wavelengths of the principal radiations from radio waves to γ-rays
6) Production and use of ultrasound in diagnosis
   a) explain the principles of the generation and detection of ultrasonic waves using piezo-electric transducers
   b) explain the main principles behind the use of ultrasound to obtain diagnostic information about internal structures
   c) understand the meaning of specific acoustic impedance and its importance to the intensity reflection coefficient at a boundary
   d) recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter

Superposition

Superposition is used to develop the concept of stationary waves.

Diffraction and interference are then studied, including two-source interference and the diffraction grating.

1) Stationary waves
   a) explain and use the principle of superposition in simple applications
   b) show an understanding of experiments that demonstrate stationary waves using microwaves, stretched strings and air columns
   c) explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes
2) Diffraction
   a) explain the meaning of the term diffraction
   b) show an understanding of experiments that demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap
3) Interference, two-source interference
   a) understand the terms interference and coherence
   b) show an understanding of experiments that demonstrate two-source interference using water ripples, light and microwaves
   c) understand the conditions required if two-source interference fringes are to be observed
   d) recall and solve problems using the equation $\lambda = ax/D$ for double-slit interference using light
4) Diffraction gratings
   a) recall and solve problems using the formula $d\sin\theta = n\lambda$

b) describe the use of a diffraction grating to determine the wavelength of light

Communication

Modern methods of communication rely heavily on waves. This topic introduces the idea of different channels of communication together with modulation of waves and digital communication.

Aspects of communication are studied through a comparison of the advantages and disadvantages of different channels of communication.

1) Communication channels
   a) appreciate that information may be carried by a number of different channels, including wire-pairs, coaxial cables, radio and microwave links, optic fibres
2) Modulation
   a) understand the term modulation and be able to distinguish between amplitude modulation (AM) and frequency modulation (FM)
   b) recall that a carrier wave, amplitude modulated by a single audio frequency, is equivalent to the carrier wave frequency together with two sideband frequencies
   c) understand the term bandwidth
   d) recall the frequencies and wavelengths used in different channels of communication
   e) demonstrate an awareness of the relative advantages of AM and FM transmissions
3) Digital communication
   a) recall the advantages of the transmission of data in digital form, compared with the transmission of data in analogue form
   b) understand that the digital transmission of speech or music involves analogue-to-digital conversion (ADC) before transmission and digital-to-analogue conversion (DAC) after reception
   c) understand the effect of the sampling rate and the number of bits in each sample on the reproduction of an input signal
4) Relative merits of channels of communication
   a) discuss the relative advantages and disadvantages of channels of communication in terms of available bandwidth, noise, crosslinking, security, signal attenuation, repeaters and regeneration
   b) recall the relative merits of both geostationary and polar orbiting satellites for communicating information
5) Attenuation
   a) understand and use signal attenuation expressed in dB and dB per unit length
   b) recall and use the expression number of dB= 10 lg (P_1/P_2) for the ratio of two powers

Electric Fields

In this topic, the concept of an electric field is introduced. This is further developed to study the field and potential energy of point charges.

Awareness of the two types of charge and the processes of charging by friction and by induction are useful prior knowledge.

1) Concept of an electric field
   a) understand the concept of an electric field as an example of a field of force and define electric field strength as force per unit positive charge acting on a stationary point charge
   b) represent an electric field by means of field lines
2) Uniform electric fields
   a) recall and use $E=\Delta V/\Delta d$ to calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation
   b) calculate the forces on charges in uniform electric fields
   c) describe the effect of a uniform electric field on the motion of charged particles
3) Electric forces between point charges
   a) understand that, for any point outside a spherical conductor, the charge on the sphere may be considered to act as a point charge at its centre
   b) recall and use Coulomb's law in the form $F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2}$ for the field strength of a point charge in free space or air

4) Electric field of a point charge
- **a) recall and use $E = \frac{Q}{4\pi\epsilon_0 r^2}$ for the field strength of a point charge in free space or air**

5) Electric potential
- **a) define potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point**
- **b) state that the field strength of the field at a point is equal to the negative of potential gradient at that point**
- **c) use the equation $V = \frac{Q}{4\pi\epsilon_0 r}$ for the potential in the field of a point charge**
- **d) recognise the analogy between certain qualitative and quantitative aspects of electric fields and gravitational fields**

Capacitance

This topic introduces the concept of capacitance, then describes the capacitor and its functions in simple circuits.

1) Capacitors and capacitance
- **a) define capacitance and the farad, as applied to both isolated conductors and to parallel plate capacitors**
- **b) recall and use C= Q/V**
- **c) derive, using the formula C= Q/V, conservation of charge and the addition of potential differences, formulae for combined capacitance for capacitors in series and in parallel**
- **d) solve problems using the capacitance formulae for capacitors in series and in parallel**

2) Energy stored in a capacitor
- **a) deduce, from the area under a potential-charge graph, the equation W=1/2 QV and hence W=1/2 CV^2**
- **b) show an understanding of the functions of capacitors in simple circuits**

Current of electricity

Electric current, potential difference, resistance and power in electrical circuits are introduced. The concept of resistivity is included. Some electrical components may be used to sense environmental changes.

1) Electric current
- a) understand that electric current is a flow of charge carriers
- b) understand that the charge on charge carriers is quantised
- c) define the coulomb
- d) recall and use Q= It
- e) derive and use, for a current-carrying conductor, the expression I= Anvq, where nis the number density of charge carriers

2) Potential difference and power
- a) define potential difference and the volt
- b) recall and use V= W/Q
- c) recall and use P= VI and P= I^2R

3) Resistance and resistivity
- a) define resistance and the ohm
- b) recall and use V= IR
- c) sketch and discuss the I–V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp
- d) state Ohm's law
- e) recall and use R= ρL/A

4) Sensing devices
- **a) show an understanding of the change in resistance with light intensity of a light-dependent resistor (LDR)**
- **b) sketch the temperature characteristic of a negative temperature coefficient thermistor**
- **c) show an understanding of the action of a piezo-electric transducer and its application in a simple microphone**

d) describe the structure of a metal-wire strain gauge
e) relate extension of a strain gauge to change in resistance of the gauge

D.C. circuits

In this topic, practical circuits are considered. Circuit diagrams are studied with particular reference to Kirchhoff's laws and the consequences of internal resistance.

The use of potential divider circuits for monitoring environmental conditions is studied

1) Practical circuits
   a) recall and use appropriate circuit symbols (see Electrical Symbols section)
   b) draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus
   c) define electromotive force (e.m.f.) in terms of the energy transferred by a source in driving unit charge round a complete circuit
   d) distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations
   e) understand the effects of the internal resistance of a source of e.m.f. on the terminal potential difference
2) Kirchhoff's laws
   a) recall Kirchhoff's first law and appreciate the link to conservation of charge
   b) recall Kirchhoff's second law and appreciate the link to conservation of energy
   c) derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series
   d) solve problems using the formula for the combined resistance of two or more resistors in series
   e) derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel
   f) solve problems using the formula for the combined resistance of two or more resistors in parallel
   g) apply Kirchhoff's laws to solve simple circuit problems
3) Potential dividers
   a) understand the principle of a potential divider circuit as a source of variable p.d.
   b) recall and solve problems using the principle of the potentiometer as a means of comparing potential differences
   c) understand that an electronic sensor consists of a sensing device and a circuit that provides an output that can be registered as a voltage
   d) explain the use of thermistors, light-dependent resistors and strain gauges in potential dividers to provide a potential difference that is dependent on temperature, illumination and strain respectively

Electronics

An introduction to electronics is provided in this topic through the study of amplifier circuits incorporating an ideal operational amplifier. In particular, emphasis is placed on sensing circuits for changes in environmental conditions.

The use of feedback to control gain is considered together with some output devices.

1) The ideal operational amplifier
   a) recall the main properties of the ideal operational amplifier (op-amp)
2) Operational amplifier circuits
   a) deduce, from the properties of an ideal operational amplifier, the use of an operational amplifier as a comparator
   b) understand the effects of negative feedback on the gain of an operational amplifier
   c) recall the circuit diagrams for both the inverting and the noninverting amplifier for single signal input
   d) understand the virtual earth approximation and derive an expression for the gain of inverting amplifiers
   e) recall and use expressions for the voltage gain of inverting and of non-inverting amplifiers
3) Output devices
   a) understand that an output device may be required to monitor the output of an op-amp circuit
   b) understand the use of relays in electronic circuits
   c) understand the use of light-emitting diodes (LEDs) as devices to indicate the state of the output of electronic circuits

d) **understand the need for calibration where digital or analogue meters are used as output devices**

Magnetic fields

The concept of a magnetic field is developed by studying the force on current-carrying conductors and on charged particles in magnetic fields.

The Hall effect and nuclear magnetic resonance imaging are studied as examples of the use of magnetic fields.

1) **Concept of a magnetic field**
   a) **understand that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets**
   b) **represent a magnetic field by field lines**
2) **Force on a current-carrying conductor**
   a) **appreciate that a force might act on a current-carrying conductor placed in a magnetic field**
   b) **recall and solve problems using the equation F= BIL sin θ, with directions as interpreted by Fleming's left-hand rule**
   c) **define magnetic flux density and the tesla**
   d) **understand how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance**
3) **Force on a moving charge**
   a) **predict the direction of the force on a charge moving in a magnetic field**
   b) **recall and solve problems using F= BQv sin θ**
   c) **derive the expression $V_H = \frac{BI}{ntq}$ for the Hall voltage, where t= thickness**
   d) **describe and analyse qualitatively the deflection of beams of charged**
   e) **particles by uniform electric and uniform magnetic fields**
   f) **explain how electric and magnetic fields can be used in velocity selection**
   g) **explain the main principles of one method for the determination of v and e/m_e for electrons**
4) **Magnetic fields due to currents**
   a) **sketch flux patterns due to a long straight wire, a flat circular coil and a long solenoid**
   b) **understand that the field due to a solenoid is influenced by the presence of a ferrous core**
   c) **explain the forces between current-carrying conductors and predict the direction of the forces**
   d) **describe and compare the forces on mass, charge and current in gravitational, electric and magnetic fields, as appropriate**
5) **Nuclear magnetic resonance imaging**
   a) **explain the main principles behind the use of nuclear magnetic resonance imaging (NMRI) to obtain diagnostic information about internal structures**
   b) **understand the function of the non-uniform magnetic field, superimposed on the large constant magnetic field, in diagnosis using NMRI**

Electromagnetic induction

Electromagnetic induction provides the basis of an important means of generating electrical power. In this topic, the laws of electromagnetic induction are developed.

1) **Laws of electromagnetic induction**
   a) **define magnetic flux and the weber**
   b) **recall and use Φ= BA**
   c) **define magnetic flux linkage**
   d) **infer from appropriate experiments on electromagnetic induction:**
      - **that a changing magnetic flux can induce an e.m.f. in a circuit**
      - **that the direction of the induced e.m.f. opposes the change producing it**
      - **the factors affecting the magnitude of the induced e.m.f.**
   e) **recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law**
   f) **explain simple applications of electromagnetic induction**

Alternating Currents

In many countries, electrical energy is supplied in the form of an alternating voltage supply. The basic terms used to describe alternating currents are introduced.

Transformers are studied, together their use in the transmission of electrical energy. Rectification and smoothing are also included.

1) **Characteristics of alternating currents**
   a) **understand and use the terms period, frequency, peak value and root-mean-square value as applied to an alternating current or voltage**
   b) **deduce that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current**
   c) **represent a sinusoidally alternating current or voltage by an equation of the form x= x0sinωt**
   d) **distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I = \frac{I_0}{\sqrt{2}}$ for the sinusoidal case**
2) **The transformer**
   a) **understand the principle of operation of a simple laminated iron-cored transformer and recall and solve problems using $\frac{N_S}{N_P} = \frac{V_S}{V_P} = \frac{I_P}{I_S}$ for an ideal transformer**
   b) **understand the sources of energy loss in a practical transformer**
3) **Transmission of electrical energy**
   a) **appreciate the practical and economic advantages of alternating current and of high voltages for the transmission of electrical energy**
4) **Rectification**
   a) **distinguish graphically between half-wave and full-wave rectification**
   b) **explain the use of a single diode for the half-wave rectification of an alternating current**
   c) **explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current**
   d) **analyse the effect of a single capacitor in smoothing, including the effect of the value of capacitance in relation to the load resistance**

Quantum physics

Quantum physics is the name given to studies involving an appreciation that some quantities are found only in discrete amounts.

The concept of a photon is established through a study of the photoelectric effect. Discrete energy levels in atoms can then be understood through line emission and absorption spectra. These ideas can then be extended to include band theory. Wave-particle duality and electron diffraction are also introduced.

An understanding of the production of X-rays involves the concept of photons. Examples of applications of X-rays are studied, including X-ray imaging and CT scanning.

1) **Energy of a photon**
   a) **appreciate the particulate nature of electromagnetic radiation**
   b) **recall and use E= hf**
2) **Photoelectric emission of electrons**
   a) **understand that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature**
   b) **recall the significance of threshold frequency**
   c) **explain photoelectric phenomena in terms of photon energy and work function energy**
   d) **explain why the maximum photoelectric energy is independent of intensity, whereas the photoelectric current is proportional to intensity**
   e) **recall, use and explain the significance of $hf = \Phi + 1/2\, mv_{max}^2$**
3) **Wave-particle duality**
   a) **describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles**
   b) **recall and use the relation for the de Broglie wavelength λ=h/p**

4) Energy levels in atoms and line spectra
   a) show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines
   b) distinguish between emission and absorption line spectra
   c) recall and solve problems using the relation hf= $E_1 - E_2$
5) Band theory
   a) appreciate that, in a simple model of band theory, there are energy bands in solids
   b) understand the terms valence band, conduction band and forbidden band (band gap)
   c) use simple band theory to explain the temperature dependence of the resistance of metals and of intrinsic semiconductors
   d) use simple band theory to explain the dependence on light intensity of the resistance of an LDR
6) Production and use of X-rays
   a) explain the principles of the production of X-rays by electron bombardment of a metal target
   b) describe the main features of a modern X-ray tube, including control of the intensity and hardness of the X-ray beam
   c) understand the use of X-rays in imaging internal body structures, including a simple analysis of the causes of sharpness and contrast in X-ray imaging
   d) recall and solve problems by using the equation $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter
   e) understand the purpose of computed tomography or CT scanning
   f) understand the principles of CT scanning
   g) understand how the image of an 8-voxel cube can be developed using CT scanning

Particle and nuclear physics

Alpha-particle scattering is studied as evidence for the structure of the atom.

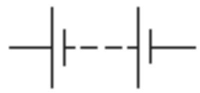
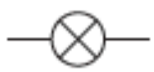
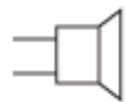
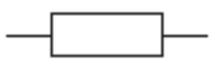
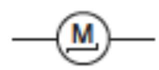
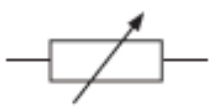
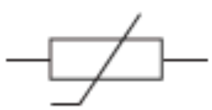
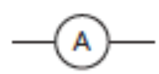
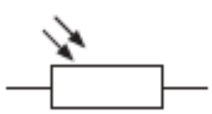
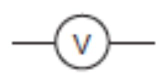
Nuclear composition, in terms of nucleons, leads to an appreciation of mass defect and binding energy. Nuclear processes including radioactive decay, fission and fusion are studied.

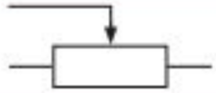
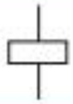
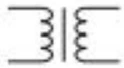
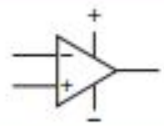
An introduction to fundamental particles is included.

1) Atoms, nuclei and radiation
   a) infer from the results of the α-particle scattering experiment the existence and small size of the nucleus
   b) describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons
   c) distinguish between nucleon number and proton number
   d) understand that an element can exist in various isotopic forms, each with a different number of neutrons
   e) use the usual notation for the representation of nuclides
   f) appreciate that nucleon number, proton number, and mass-energy are all conserved in nuclear processes
   g) show an understanding of the nature and properties of α-, β- and γ-radiations (both β–and β+ are included)
   h) state that (electron) antineutrinos and (electron) neutrinos are produced during β– and β+ decay
2) Fundamental particles
   a) appreciate that protons and neutrons are not fundamental particles since they consist of quarks
   b) describe a simple quark model of hadrons in terms of up, down and strange quarks and their respective antiquarks
   c) describe protons and neutrons in terms of a simple quark model
   d) appreciate that there is a weak interaction between quarks, giving rise to β decay
   e) describe β– and β+ decay in terms of a simple quark model
   f) appreciate that electrons and neutrinos are leptons
3) Mass defect and nuclear binding energy
   a) show an appreciation of the association between energy and mass as represented by $E= mc^2$ and recall and use this relationship
   b) understand the significance of the terms mass defect and mass excess in nuclear reactions
   c) represent simple nuclear reactions by nuclear equations of the form $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$
   d) define and understand the terms mass defect and binding energy
   e) sketch the variation of binding energy per nucleon with nucleon number
   f) explain what is meant by nuclear fusion and nuclear fission
   g) explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission
4) Radioactive decay

a) infer the random nature of radioactive decay from the fluctuations in count rate
b) show an appreciation of the spontaneous and random nature of nuclear decay
c) define the terms activity and decay constant and recall and solve problems using A= λN
d) infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $x = x_0 e^{-\lambda t}$
e) where x could represent activity, number of undecayed nuclei or received count rate
f) define half-life
g) solve problems using the relation $\lambda = 0.693/t_{1/2}$

Electrical Symbols

cell		switch	
battery of cells	 or 	earth or ground	
power supply		electric bell	
a.c. power supply		buzzer	
junction of conductors		microphone	
lamp		loudspeaker	
fixed resistor		motor	
variable resistor		generator	
thermistor		ammeter	
light dependent resistor		voltmeter	
heater		galvanometer	

potentiometer		oscilloscope	
relay coil		antenna	
transformer		capacitor	
diode		operational amplifier	
light-emitting diode			

Symbols and Units

The list below is intended as a guide to the more important quantities which might be encountered in teaching and used in question papers. This list is for use in both AS Level and full A Level qualifications.

Quantity	Usual symbols	Usual unit
Base quantities		
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other quantities		
acceleration	a	$m\,s^{-2}$
acceleration of free fall	g	$m\,s^{-2}$
activity of radioactive source	A	Bq
amplitude	x_0	m
angle	θ	°, rad
angular displacement	θ	°, rad
angular frequency	ω	$rad\,s^{-1}$
angular speed	ω	$rad\,s^{-1}$
angular velocity	ω	$rad\,s^{-1}$
area	A	m^2
atomic mass	m_a	kg, u
attenuation/absorption coefficient	μ	m^{-1}
Avogadro constant	N_A	mol^{-1}
Boltzmann constant	k	$J\,K^{-1}$
capacitance	C	F
Celsius temperature	θ	°C
decay constant	λ	s^{-1}
density	ρ	$kg\,m^{-3}$
displacement	s, x	m
distance	d	m
efficiency	η	
electric charge	q, Q	C

Quantity	Usual symbols	Usual unit
electric field strength	E	$N C^{-1}$, $V m^{-1}$
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
electron mass	m_e	kg, u
elementary charge	e	C
energy	E, U, W	J
force	F	N
frequency	f	Hz
gravitational constant	G	$N m^2 kg^{-2}$
gravitational field strength	g	$N kg^{-1}$
gravitational potential	ϕ	$J kg^{-1}$
half-life	$t_{\frac{1}{2}}$	s
Hall voltage	V_H	V
heating	q, Q	J
intensity	I	$W m^{-2}$
internal energy change	ΔU	J
kinetic energy	E_k	J
magnetic flux	Φ	Wb
magnetic flux density	B	T
mean-square speed	$\langle c^2 \rangle$	$m^2 s^{-2}$
molar gas constant	R	$J mol^{-1} K^{-1}$
molar mass	M	$kg mol^{-1}$
moment of force	T	N m
momentum	p	N s
neutron mass	m_n	kg, u
neutron number	N	
nucleon number	A	
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
period	T	s
permeability of free space	μ_0	$H m^{-1}$
permittivity of free space	ε_0	$F m^{-1}$
phase difference	ϕ	°, rad
Planck constant	h	J s
potential energy	E_p	J

Quantity	Usual symbols	Usual unit
power	P	W
pressure	p	Pa
proton mass	m_p	kg, u
proton number	Z	
ratio of powers		dB
relative atomic mass	A_r	
relative molecular mass	M_r	
resistance	R	Ω
resistivity	ρ	Ω m
specific acoustic impedance	Z	$kg\,m^{-2}\,s^{-1}$
specific heat capacity	c	$J\,kg^{-1}\,K^{-1}$
specific latent heat	L	$J\,kg^{-1}$
speed	u, v, w, c	$m\,s^{-1}$
speed of electromagnetic waves	c	$m\,s^{-1}$
spring constant	k	$N\,m^{-1}$
strain	ε	
stress	σ	Pa
torque	T	N m
velocity	u, v, w, c	$m\,s^{-1}$
volume	V, v	m^3
wavelength	λ	m
weight	W	N
work	w, W	J
work function energy	Φ	J
Young modulus	E	Pa

Data and Formulae

The following data and formulae will appear as pages 2 and 3 in Papers 1, 2 (AS Test) and 4 (A Test). Some of the data and formulae will not be needed for the AS Papers.

Data

speed of light in free space	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
	$(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \mathrm{m\,F^{-1}})$
elementary charge	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass unit	$1\,\mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
gravitational potential	$\phi = -\frac{Gm}{r}$
hydrostatic pressure	$p = \rho g h$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy of charged capacitor	$W = \frac{1}{2}QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$