A Level subject content

12 Motion in a circle

12.1 Kinematics of uniform circular motion

Candidates should be able to:

$$\Delta\theta = \frac{\textit{distance travelled around the circle}}{\textit{radius of the circle}}$$

1 define the radian and express angular displacement in radians

2 understand and use the concept of angular speed

3 recall and use $\omega = 2\pi / T$ and $v = r\omega$

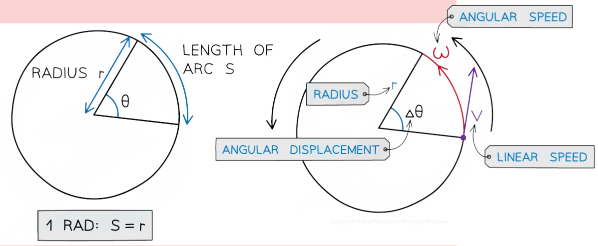
$= 2\pi \frac{1}{T}$

$= 2\pi f$

$\theta = \frac{d}{r}$, $v = \frac{d}{t}$

$\omega = \frac{\theta}{t} = \frac{d}{rt} = \frac{v}{r}$

$\therefore v = r\omega$



12.2 Centripetal acceleration

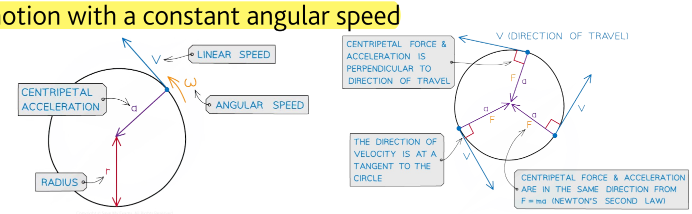
Candidates should be able to:

1 understand that a force of constant magnitude that is always perpendicular to the direction of motion causes centripetal acceleration **## centripetal acceleration is perpendicular to the direction of the linear speed**

2 understand that centripetal acceleration causes circular motion with a constant angular speed

3 recall and use $a = r\omega^2$ and $a = v^2 / r$, $a = \frac{v^2}{\left(\frac{v}{\omega}\right)} = v\omega$

4 recall and use $F = mr\omega^2$ and $F = mv^2 / r$ $\therefore a = v\omega$



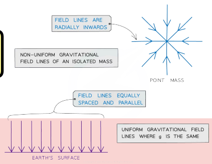
13 Gravitational fields

13.1 Gravitational field

Candidates should be able to:

1 understand that a gravitational field is an example of a field of force and define gravitational field (strength) as force per unit mass

2 represent a gravitational field by means of field lines



13.2 Gravitational force between point masses

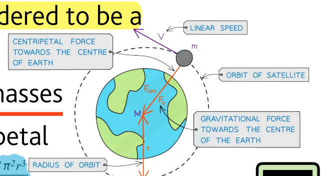
Candidates should be able to:

1 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

2 recall and use Newton's law of gravitation $F = Gm_1m_2 / r^2$ for the force between two point masses

3 analyse circular orbits in gravitational fields by relating the gravitational force to the centripetal acceleration it causes $F_G = F_{circ}$ $\frac{GMm}{r^2} = \frac{mv^2}{r}$ $v^2 = \frac{GM}{r}$ This means that all satellites, whatever their mass, will travel at the same speed v in a particular orbit radius r | $v = \frac{2\pi r}{T}$ $v^2 = \left(\frac{2\pi r}{T}\right)^2 = \frac{GM}{r}$ $T^2 = \frac{4\pi^2 r^3}{GM}$

↳ Used to derive most formulae in QPs



4 understand that a satellite in a geostationary orbit remains at the same point above the Earth's surface, with an orbital period of 24 hours, orbiting from west to east, directly above the Equator

13.3 Gravitational field of a point mass

Candidates should be able to:

1 derive, from Newton's law of gravitation and the definition of gravitational field, the equation $g = GM / r^2$ for the gravitational field strength due to a point mass

i) $F_G = \frac{GMm}{r^2}$

ii) $g = \frac{F}{m}$ … $F = mg$

$F = F_G$

$\cancel{m}g = \frac{GM\cancel{m}}{r^2}$

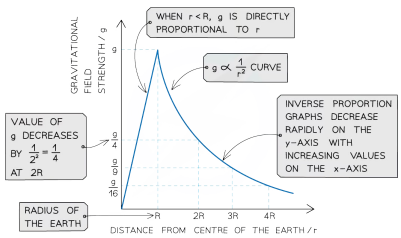
$\therefore g = \frac{GM}{r^2}$

2 recall and use $g = GM / r^2$

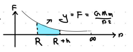
3 understand why g is approximately constant for small changes in height near the Earth's surface

$$g = \frac{GM}{(R+h)^2} \simeq \frac{GM}{R^2}$$

The value of g increases in direct proportion to distance from the centre of the Earth until the Earth's surface, then it decreases with distance at an increasing rate



• When an object moves from Low potential to High potential, the workdone is +ve
• When an object moves from High potential to Low potential, the workdone is −ve



Deriving graph from F/r graph
↳ Calculating change in GPE when mass m lifted height h above the surface

ΔE_p = Area under graph

$= \int_{R}^{R+h} GMmr^{-2}\,dr$

$= -\frac{GMm}{R+h} - \left(-\frac{GMm}{R}\right)$

$= GMm\left(\frac{1}{R} - \frac{1}{R+h}\right) = GMm\left(\frac{R+h-R}{R(R+h)}\right)$

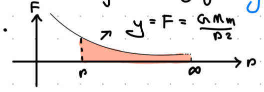
since h is negligible compared to R, $R+h \approx R$

$= GMm\left(\frac{h}{R^2}\right) = \frac{GMmh}{R^2}$

$F = \frac{GMm}{R^2}$ and $F = mg$, thus

$= Fh$

$= mgh$ (shown)



workdone to move point mass of m kg from ∞ to r is area under the graph

$\int_{\infty}^{r} GMmr^{-2}\,dr$ (r: Final, ∞: Initial)

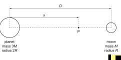
$= \left[\frac{GMmr^{-1}}{-1}\right]_{\infty}^{r}$

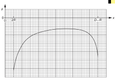
$= -\frac{GMm}{r} - \left(-\frac{GMm}{\infty}\right)$

$= -\frac{GMm}{r} + 0$

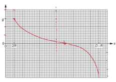
$= -\frac{GMm}{r}$

• Gravitational Potential Energy (E_p) is the highest at ∞.
• Gravitational Potential is just E_p/m
• Conventionally (and Mathematically), we consider Ø at ∞ to be 0. Thus Ø keeps becoming less −ve as r increases until it finally becomes 0 at ∞
• As r increases, Ø increases





potential at (surface of) planet is smaller than at (surface of) moon potential gradient at (surface of) planet is smaller than at (surface of) moon magnitude of potential varies inversely with distance from centre near the spheres (point of) maximum potential is nearer to moon than planet



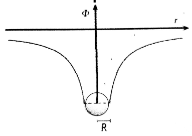
13.4 Gravitational potential

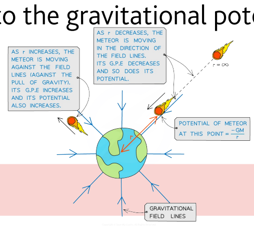
Candidates should be able to:

1 define gravitational potential at a point as the work done per unit mass in bringing a small test mass from infinity to the point

2 use $\phi = -GM / r$ for the gravitational potential in the field due to a point mass

3 understand how the concept of gravitational potential leads to the gravitational potential energy of two point masses and use $E_P = -GMm / r$





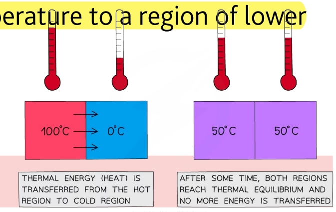
14 Temperature

14.1 Thermal equilibrium

Candidates should be able to:

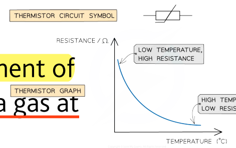
1 understand that (thermal) energy is transferred from a region of higher temperature to a region of lower temperature

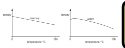
2 understand that regions of equal temperature are in thermal equilibrium



14.2 Temperature scales

Candidates should be able to:

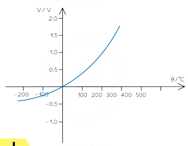




1 understand that a physical property that varies with temperature may be used for the measurement of temperature and state examples of such properties, including the density of a liquid, volume of a gas at constant pressure, resistance of a metal, e.m.f. of a thermocouple

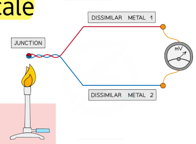
2 understand that the scale of thermodynamic temperature does not depend on the property of any particular substance

For example how the Celsius scale depends on the freezing and boiling points of water, the thermodynamic scale is not dependent on any such property of any substance

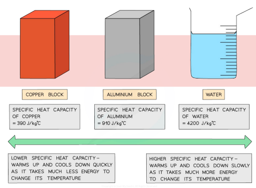


3 convert temperatures between kelvin and degrees Celsius and recall that $T / \mathrm{K} = \theta / {}^{\circ}\mathrm{C} + 273.15$

4 understand that the lowest possible temperature is zero kelvin on the thermodynamic temperature scale and that this is known as absolute zero



14.3 Specific heat capacity and specific latent heat

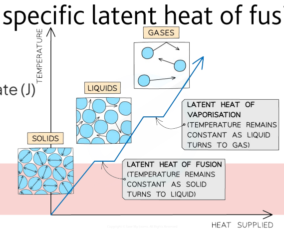


Candidates should be able to:

1 define and use specific heat capacity $\Delta Q = mc\Delta\theta$

2 define and use specific latent heat and distinguish between specific latent heat of fusion and specific latent heat of vaporisation $Q = Lm$

- Q = amount of thermal energy to change the state (J)
- L = latent heat of fusion or vaporisation ($\mathrm{J\,kg^{-1}}$)
- m = mass of the substance changing state (kg)



15 Ideal gases

15.1 The mole

Candidates should be able to:

1 understand that amount of substance is an SI base quantity with the base unit mol

2 use molar quantities where one mole of any substance is the amount containing a number of particles of that substance equal to the Avogadro constant N_A

15.2 Equation of state

Candidates should be able to:

1 understand that a gas obeying $pV \propto T$, where T is the thermodynamic temperature, is known as an ideal gas

2 recall and use the equation of state for an ideal gas expressed as $pV = nRT$, where n = amount of substance (number of moles) and as $pV = NkT$, where N = number of molecules

3 recall that the Boltzmann constant k is given by $k = R / N_A$

↳ unit: JK^{-1}

15.3 Kinetic theory of gases

Candidates should be able to:

1 state the basic assumptions of the kinetic theory of gases

2 explain how molecular movement causes the pressure exerted by a gas and derive and use the relationship $pV = \frac{1}{3}Nm\langle c^2\rangle$, where $\langle c^2\rangle$ is the mean-square speed (a simple model considering one-dimensional collisions and then extending to three dimensions using $\frac{1}{3}\langle c^2\rangle = \langle c_x^2\rangle$ is sufficient)

3 understand that the root-mean-square speed $c_{r.m.s.}$ is given by $\sqrt{\langle c^2\rangle}$

4 compare $pV = \frac{1}{3}Nm\langle c^2\rangle$ with $pV = NkT$ to deduce that the average translational kinetic energy of a molecule is $\frac{3}{2}kT$

$pV = NkT \ldots (i)$
$pV = \frac{1}{3}Nm\langle c^2\rangle \ldots (ii)$

$\therefore \frac{1}{3}Nm\langle c^2\rangle = NkT$

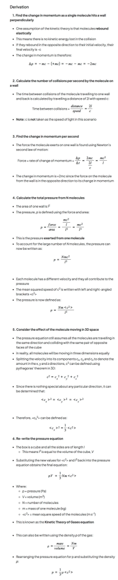
$m\langle c^2\rangle = 3kT$

since $E_k = \frac{1}{2}mv^2$,

$E_k = \frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$

↳ average kinetic energy of 1 molecule

- E_K = kinetic energy of a molecule (J)
- m = mass of one molecule (kg)
- $\langle c^2\rangle$ = mean square speed of a molecule ($m^2 s^{-2}$)
- k = Boltzmann constant
- T = temperature of the gas (K)



16 Thermodynamics

An understanding of energy from Cambridge IGCSE/O Level Physics or equivalent is assumed.

16.1 Internal energy

Candidates should be able to:

1 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

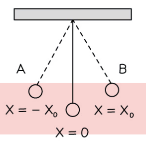
2 relate a rise in temperature of an object to an increase in its internal energy

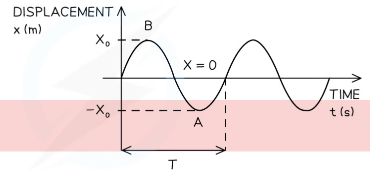
16.2 The first law of thermodynamics

Candidates should be able to:

1 recall and use $W = p\Delta V$ for the work done when the volume of a gas changes at constant pressure and understand the difference between the work done by the gas and the work done on the gas

2 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

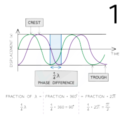




17 Oscillations

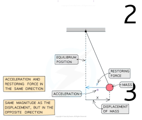
17.1 Simple harmonic oscillations

Candidates should be able to:



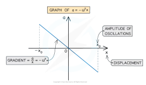
1 understand and use the terms displacement, amplitude, period, frequency, angular frequency and phase difference in the context of oscillations, and express the period in terms of both frequency and angular frequency

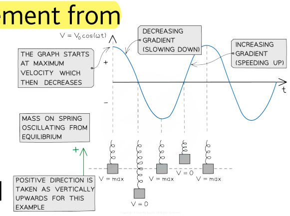
$T = \frac{1}{f} = \frac{2\pi}{\omega}$



2 understand that simple harmonic motion occurs when acceleration is proportional to displacement from a fixed point and in the opposite direction

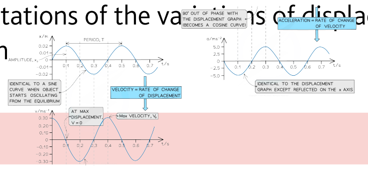
3 use $a = -\omega^2 x$ and recall and use, as a solution to this equation, $x = x_0 \sin \omega t$





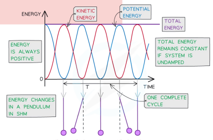
4 use the equations $v = v_0 \cos \omega t$ and $v = \pm\omega\sqrt{(x_0^2 - x^2)}$ Maximum speed occurs when x=0 $v_0 = \omega x_0$

5 analyse and interpret graphical representations of the variations of displacement, velocity and acceleration for simple harmonic motion



17.2 Energy in simple harmonic motion

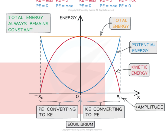
Candidates should be able to:



1 describe the interchange between kinetic and potential energy during simple harmonic motion

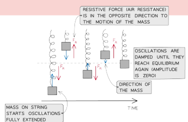
2 recall and use $E = \frac{1}{2}m\omega^2 {x_0}^2$ for the total energy of a system undergoing simple harmonic motion

$E = E_{k\,max}$ where v is maximum thy $v = \omega x_0$



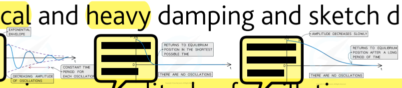
17.3 Damped and forced oscillations, resonance

Candidates should be able to:

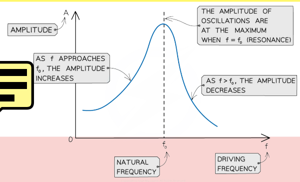


1 understand that a resistive force acting on an oscillating system causes damping

2 understand and use the terms light, critical and heavy damping and sketch displacement–time graphs illustrating these types of damping



3 understand that resonance involves a maximum amplitude of oscillations and that this occurs when an oscillating system is forced to oscillate at its natural frequency



18 Electric fields

18.1 Electric fields and field lines

Candidates should be able to:

1 understand that an electric field is an example of a field of force and define electric field as force per unit positive charge

2 recall and use $F = qE$ for the force on a charge in an electric field

3 represent an electric field by means of field lines

18.2 Uniform electric fields

Candidates should be able to:

1 recall and use $E = \Delta V / \Delta d$ to calculate the field strength of the uniform field between charged parallel plates

2 describe the effect of a uniform electric field on the motion of charged particles

18.3 Electric force between point charges

Candidates should be able to:

1. understand that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its centre
2. recall and use Coulomb's law $F = Q_1Q_2 / (4\pi\varepsilon_0 r^2)$ for the force between two point charges in free space

18.4 Electric field of a point charge

Candidates should be able to:

1. recall and use $E = Q / (4\pi\varepsilon_0 r^2)$ for the electric field strength due to a point charge in free space

18.5 Electric potential

Candidates should be able to:

1. define electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to the point
2. recall and use the fact that the electric field at a point is equal to the negative of potential gradient at that point
3. use $V = Q / (4\pi\varepsilon_0 r)$ for the electric potential in the field due to a point charge
4. understand how the concept of electric potential leads to the electric potential energy of two point charges and use $E_P = Qq / (4\pi\varepsilon_0 r)$

19 Capacitance

19.1 Capacitors and capacitance

Candidates should be able to:

1. define capacitance, as applied to both isolated spherical conductors and to parallel plate capacitors
2. recall and use $C = Q / V$
3. derive, using $C = Q / V$, formulae for the combined capacitance of capacitors in series and in parallel
4. use the capacitance formulae for capacitors in series and in parallel

19.2 Energy stored in a capacitor

Candidates should be able to:

1. determine the electric potential energy stored in a capacitor from the area under the potential–charge graph
2. recall and use $W = \frac{1}{2}QV = \frac{1}{2}CV^2$

19.3 Discharging a capacitor

Candidates should be able to:

1. analyse graphs of the variation with time of potential difference, charge and current for a capacitor discharging through a resistor
2. recall and use $\tau = RC$ for the time constant for a capacitor discharging through a resistor
3. use equations of the form $x = x_0\,e^{-(t/RC)}$ where x could represent current, charge or potential difference for a capacitor discharging through a resistor

20 Magnetic fields

20.1 Concept of a magnetic field

Candidates should be able to:

1 understand that a magnetic field is an example of a field of force produced either by moving charges or by permanent magnets

2 represent a magnetic field by field lines

20.2 Force on a current-carrying conductor

Candidates should be able to:

1 understand that a force might act on a current-carrying conductor placed in a magnetic field

2 recall and use the equation $F = BIL \sin \theta$, with directions as interpreted by Fleming's left-hand rule

3 define magnetic flux density as the force acting per unit current per unit length on a wire placed at right-angles to the magnetic field

20.3 Force on a moving charge

Candidates should be able to:

1 determine the direction of the force on a charge moving in a magnetic field

2 recall and use $F = BQv \sin \theta$

3 understand the origin of the Hall voltage and derive and use the expression $V_H = BI / (ntq)$, where t = thickness

4 understand the use of a Hall probe to measure magnetic flux density

5 describe the motion of a charged particle moving in a uniform magnetic field perpendicular to the direction of motion of the particle

6 explain how electric and magnetic fields can be used in velocity selection

20.4 Magnetic fields due to currents

Candidates should be able to:

1 sketch magnetic field patterns due to the currents in a long straight wire, a flat circular coil and a long solenoid

2 understand that the magnetic field due to the current in a solenoid is increased by a ferrous core

3 explain the origin of the forces between current-carrying conductors and determine the direction of the forces

20.5 Electromagnetic induction

Candidates should be able to:

1 define magnetic flux as the product of the magnetic flux density and the cross-sectional area perpendicular to the direction of the magnetic flux density

2 recall and use $\Phi = BA$

3 understand and use the concept of magnetic flux linkage

4 understand and explain experiments that demonstrate:
- that a changing magnetic flux can induce an e.m.f. in a circuit
- that the induced e.m.f. is in such a direction as to oppose the change producing it
- the factors affecting the magnitude of the induced e.m.f.

5 recall and use Faraday's and Lenz's laws of electromagnetic induction

21 Alternating currents

An understanding of the practical and economic advantages of transmission of power by electricity from Cambridge IGCSE / O Level Physics or equivalent is assumed.

21.1 Characteristics of alternating currents

Candidates should be able to:

1 understand and use the terms period, frequency and peak value as applied to an alternating current or voltage

2 use equations of the form $x = x_0 \sin \omega t$ representing a sinusoidally alternating current or voltage

3 recall and use the fact that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current

4 distinguish between root-mean-square (r.m.s.) and peak values and recall and use $I_{\text{r.m.s.}} = I_0 / \sqrt{2}$ and $V_{\text{r.m.s.}} = V_0 / \sqrt{2}$ for a sinusoidal alternating current

21.2 Rectification and smoothing

Candidates should be able to:

1 distinguish graphically between half-wave and full-wave rectification

2 explain the use of a single diode for the half-wave rectification of an alternating current

3 explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current

4 analyse the effect of a single capacitor in smoothing, including the effect of the values of capacitance and the load resistance

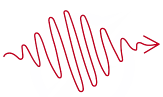
22 Quantum physics

22.1 Energy and momentum of a photon

Candidates should be able to:

1 understand that electromagnetic radiation has a particulate nature

2 understand that a photon is a quantum of electromagnetic energy



E = hf

3 recall and use $E = hf$ $\quad E = \frac{hc}{\lambda}$

4 use the electronvolt (eV) as a unit of energy $\quad eV = \frac{1}{2}mv^2,\ v = \sqrt{\frac{2eV}{m}}$

5 understand that a photon has momentum and that the momentum is given by $p = E / c$ $\quad , p = \frac{h}{\lambda}$

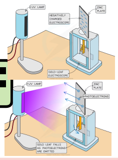
a photon travelling in a vacuum has momentum, despite it having no mass

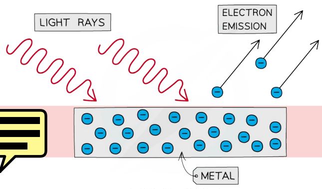
- Where:
  - p = momentum (kg m s^{-1})
  - E = energy of a photon (J)
  - c = speed of light

$E = \frac{hc}{\lambda}$

$\frac{E}{c} = \frac{h}{\lambda}$

$p = \frac{h}{\lambda}$





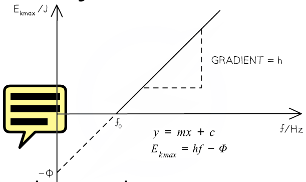
22.2 Photoelectric effect

Candidates should be able to:

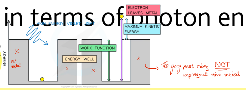
1 understand that photoelectrons may be emitted from a metal surface when it is illuminated by electromagnetic radiation

2 understand and use the terms threshold frequency and threshold wavelength

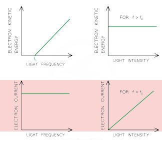
3 explain photoelectric emission in terms of photon energy and work function energy Φ



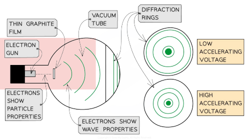
4 recall and use $hf = \Phi + \frac{1}{2}mv_{max}^2$



5 explain why the maximum kinetic energy of photoelectrons is independent of intensity, whereas the photoelectric current is proportional to intensity

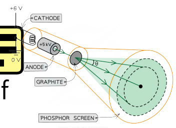


22.3 Wave-particle duality



Candidates should be able to:

1 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

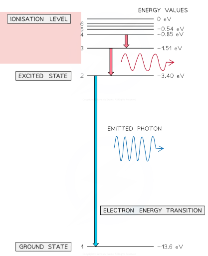


2 describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles

3 understand the de Broglie wavelength as the wavelength associated with a moving particle -ms

4 recall and use $\lambda = h/p$, $\lambda = \frac{h}{mv}$, $\lambda = \frac{h}{\sqrt{2mE}}$

22.4 Energy levels in atoms and line spectra



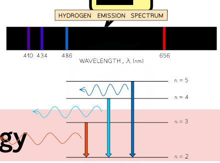
Candidates should be able to:

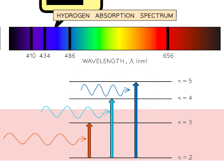
1 understand that there are discrete electron energy levels in isolated atoms (e.g. atomic hydrogen)

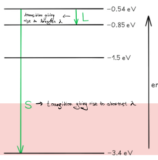
2 understand the appearance and formation of emission and absorption line spectra

3 recall and use $hf = E_1 - E_2$ $\lambda = \frac{hc}{E_2 - E_1}$

$\Delta E = hf = E_2 - E_1$







Each electron can emit more than one photon

23 Nuclear physics

23.1 Mass defect and nuclear binding energy

Candidates should be able to:

1 understand the equivalence between energy and mass as represented by $E = mc^2$ and recall and use this equation

2 represent simple nuclear reactions by nuclear equations of the form ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$

3 define and use the terms mass defect and binding energy

4 sketch the variation of binding energy per nucleon with nucleon number

5 explain what is meant by nuclear fusion and nuclear fission

6 explain the relevance of binding energy per nucleon to nuclear reactions, including nuclear fusion and nuclear fission

7 calculate the energy released in nuclear reactions using $E = c^2\Delta m$

23.2 Radioactive decay

Candidates should be able to:

1 understand that fluctuations in count rate provide evidence for the random nature of radioactive decay
2 understand that radioactive decay is both spontaneous and random
3 define activity and decay constant, and recall and use $A = \lambda N$
4 define half-life
5 use $\lambda = 0.693 / t_{\frac{1}{2}}$
6 understand the exponential nature of radioactive decay, and sketch and use the relationship $x = x_0 e^{-\lambda t}$, where x could represent activity, number of undecayed nuclei or received count rate

24 Medical physics

24.1 Production and use of ultrasound

Candidates should be able to:

1 understand that a piezo-electric crystal changes shape when a p.d. is applied across it and that the crystal generates an e.m.f. when its shape changes
2 understand how ultrasound waves are generated and detected by a piezoelectric transducer
3 understand how the reflection of pulses of ultrasound at boundaries between tissues can be used to obtain diagnostic information about internal structures
4 define the specific acoustic impedance of a medium as $Z = \rho c$, where c is the speed of sound in the medium
5 use $I_R / I_0 = (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ for the intensity reflection coefficient of a boundary between two media
6 recall and use $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter

24.2 Production and use of X-rays

Candidates should be able to:

1 explain that X-rays are produced by electron bombardment of a metal target and calculate the minimum wavelength of X-rays produced from the accelerating p.d.
2 understand the use of X-rays in imaging internal body structures, including an understanding of the term contrast in X-ray imaging
3 recall and use $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter
4 understand that computed tomography (CT) scanning produces a 3D image of an internal structure by first combining multiple X-ray images taken in the same section from different angles to obtain a 2D image of the section, then repeating this process along an axis and combining 2D images of multiple sections

24.3 PET scanning

Candidates should be able to:

1 understand that a tracer is a substance containing radioactive nuclei that can be introduced into the body and is then absorbed by the tissue being studied
2 recall that a tracer that decays by β^+ decay is used in positron emission tomography (PET scanning)
3 understand that annihilation occurs when a particle interacts with its antiparticle and that mass-energy and momentum are conserved in the process
4 explain that, in PET scanning, positrons emitted by the decay of the tracer annihilate when they interact with electrons in the tissue, producing a pair of gamma-ray photons travelling in opposite directions
5 calculate the energy of the gamma-ray photons emitted during the annihilation of an electron-positron pair
6 understand that the gamma-ray photons from an annihilation event travel outside the body and can be detected, and an image of the tracer concentration in the tissue can be created by processing the arrival times of the gamma-ray photons

25 Astronomy and cosmology

25.1 Standard candles

Candidates should be able to:

1 understand the term luminosity as the total power of radiation emitted by a star
2 recall and use the inverse square law for radiant flux intensity F in terms of the luminosity L of the source $F = L / (4\pi d^2)$
3 understand that an object of known luminosity is called a standard candle
4 understand the use of standard candles to determine distances to galaxies

25.2 Stellar radii

Candidates should be able to:

1 recall and use Wien's displacement law $\lambda_{max} \propto 1 / T$ to estimate the peak surface temperature of a star
2 use the Stefan–Boltzmann law $L = 4\pi\sigma r^2 T^4$
3 use Wien's displacement law and the Stefan–Boltzmann law to estimate the radius of a star

25.3 Hubble's law and the Big Bang theory

Candidates should be able to:

1 understand that the lines in the emission spectra from distant objects show an increase in wavelength from their known values
2 use $\Delta\lambda / \lambda \approx \Delta f / f \approx v / c$ for the redshift of electromagnetic radiation from a source moving relative to an observer
3 explain why redshift leads to the idea that the Universe is expanding
4 recall and use Hubble's law $v \approx H_0 d$ and explain how this leads to the Big Bang theory (candidates will only be required to use SI units)