**IGCSE PHYSICS: KNOW YOUR DEFINITIONS!**

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**MECHANICS**

Displacement, velocity and acceleration are **vector** quantities. The definitions here refer to a particular direction (e.g. horizontal, or vertical). **Displacement** is the ***area*** under a (**time**, **velocity**) graph, where a *negative area means a negative displacement*. **Average speed = total distance travelled / total time taken**. **Velocity** is the ***gradient*** of a (**time**, **displacement**) graph. **Acceleration** is the ***gradient*** of the (**time**, **velocity**) graph.

Q1. A sprinter runs at 5m/s for 5s, then increases speed at constant acceleration to 10m/s in 5s. This is held for 5s. The sprinter then decelerates to 9m/s in the final 5s before slowing down very rapidly. (i) Sketch this motion in a time vs velocity graph. (ii) Sketch an acceleration (in m/s) vs time graph. (iii) Calculate the total displacement in m. (iv) Sketch a displacement vs time graph.

**Newton's First Law:** A object will move at *constant velocity* if it is *not accelerating*, and therefore the vector sum of forces is zero. It is in ***equilibrium***.

**Newton's Second Law: mass × acceleration = vector sum of forces** $m\mathbf{a} = \sum_i \mathbf{f}_i$

**Weight: gravitational force = mass × acceleration due to gravity** $W = mg$

Q2. Calculate the weight (in N) of a 75kg astronaut on (i) Earth and (ii) Mars $g_{earth} = 9.81\text{N/kg}$, $g_{mars} = 3.72\text{N/kg}$

Q3. A space probe of mass 1000kg at the surface of Jupiter has the same weight of a 6664kg spacecraft on the surface of Mars. What is $g_{jupiter}$?

Q4. In $x, y$ coordinates, the forces acting on an 80kg Jedi knight in a non-light sabre battle with the Sith are (in kN): $\mathbf{f}_1 = (3,4)$, $\mathbf{f}_2 = (0,-2)$, $\mathbf{f}_3 = (F_x, F_y)$. (i) Calculate what $F_x, F_y$ need to be, such that the knight is in equilibrium. (ii) If $\mathbf{f}_3 = (-4,-1)$, determine the acceleration of the Jedi (in magnitude and direction). Make sure you draw a force diagram first.

**Elastic force: restoring force = spring constant × extension** $F = kx$

Q5. I stretch two identical springs in *series* with a force of 40N. The total stretch of both springs is 20cm. What is the spring constant $k$ of each spring in N/m?

Q6. I stretch two springs of spring constant 50N/m connected in *parallel* with a force of 25N. What is the extension of each spring in cm?

**Newton's Third Law:** If body A imposes a contact force $\mathbf{F}$ upon body B, body B will in turn impose a contact force $-\mathbf{F}$ upon body A.

Q7. A gymnast in training stands with arms aloft on a large spherical fitball. For a short time the gymnast is in equilibrium. Draw a pair of diagrams with forces acting on (i) the gymnast and (ii) the fitball.

**Moment** of a force is **force × perpendicular distance from a rotation axis**. In **equilibrium**, the sum of moments (clockwise or anticlockwise) is **zero**, regardless of the axis position chosen!

Q8. Boris (mass 100kg) sits 60cm to the right of a see-saw pivot. Emily (mass 75kg) sits 100cm to the left, and Kier (mass 85kg) sits 40cm behind her. How far must Dominic (mass 72kg) sit behind Boris to stop the see-saw tipping to the left?

**Equations of constant acceleration motion:** $u$ initial velocity, $a$ acceleration, $t$ time, $v$ final velocity, $x$ displacement, $x_0$ initial displacement

$v = u + at,\ \ x = x_0 + \frac{1}{2}(u+v)t,\ \ x = x_0 + ut + \frac{1}{2}at^2,\ \ v^2 = u^2 + 2ax$

Q9. A bullet is fired at 370m/s horizontally into some Kevlar armour, which causes it to stop within 5mm. (i) Calculate the acceleration of the bullet in the armour in m/s$^2$. (ii) Calculate the stopping time in s. (Use standard form).

For **projectile motion**, in the ***y*** direction the acceleration **is** $g = 9.81\text{ms}^{-2}$ *downwards*, and 0 ms$^{-2}$ in the **x** direction i.e. a **constant velocity in the *x* direction.**

Q10. The winner of the 2019 Red Bull Cliff Diving event in Mostar, Bosnia did a perfect 10 dive from the Stari Most bridge, a height of 24.0m above the river Neretva. Assuming he fell from rest and air resistance can be ignored, calculate (i) his time /s in the air and (ii) the speed in m/s that he hit the river.

**Conservation of momentum:** The **vector sum** of **mass** $\times$ **velocity** over all objects in a collision is the **same** after the collision. (Although the momenta of individual objects might change in the event).

Q11. In *The Blues Brothers*, Jake and Elwood's car (mass 2000kg), going at 55mph, crashes into a police car (mass 2500kg) moving at 10mph in the opposite direction. (i) If both the cars move together after the crash, calculate the resulting speed of the cars. (ii) If instead they collide elastically, calculate the velocities of both cars after the collision.

**Impulse** is a **change** in **momentum**, and the ***area*** under a (**time**, **force**) graph

Q12. The bullet in Q9 has a mass of 0.03kg. Calculate the impulse provided to it by the Kevlar armour. Also calculate the average force acting on it.

**Conservation of energy: Kinetic energy + gravitational potential energy + elastic potential energy + ....** is a **constant** in a closed system.

**Kinetic energy:** $\frac{1}{2}mv^2$ **Gravitational Potential Energy:** $mgh$ **Elastic potential energy:** $\frac{1}{2}kx^2$

Q13. Lewis Hamilton is thrown into the air (height gain 30.0cm) by his team mates to celebrate his sixth Formula 1 world title. If his maximum gravitational potential energy is 200J, what is his mass in kg?

Q14. Usain Bolt (mass 94kg) ran the 200m in 19.19s in the Berlin 2009 World Championships. Calculate his average speed and hence determine his average kinetic energy in J.

Q15. A coin is dropped down 49.1m well shaft in Carisbrooke Castle on the Isle of Wight. By considering the GPE to KE conversion, calculate the speed that the coin reaches the water at the bottom of the well.

**Work done** = ***area*** under a (**displacement**, **force**) graph

**Power** = **rate** of use of **energy**. For a moving vehicle, **power = driving force** $\times$ **velocity**

Q16. A world class cyclist can produce 400W of power over the course of an hour. If the cyclist is travelling at 12m/s, what is the driving force on the bike? How much energy (in J) is expended in total?

**ELECTRICITY & MAGNETISM**

**Ohm's Law:** $V$ **Voltage** or **'potential difference'** *across* a resistive element is proportional to **current** $I$ that flows through it. i.e. $V = IR$ . The constant of proportionality $R$ is the **resistance** (in ohms $\Omega$ ).

**Electrical Power** $P = VI$ $P$ power, $V$ voltage, $I$ current

**Resistive power loss:** $P = I^2 R$ $P$ power, $I$ current, $R$ resistance

**Resistance of a wire:** $R = \frac{\rho l}{A}$

$R$ **resistance**, $l$ **length**, $A$ **cross sectional area**, $\rho$ **resistivity**. Assume uniform resistivity and cross sectional area along length of wire. Copper: $\rho$ = 1.68 × $10^{-8}$, Aluminium : $\rho$ = 2.82 × $10^{-8}$ Ωm

Addition of **resistors** wired in **series**: $R = R_1 + R_2 + ...$

Addition of **resistors** wired in **parallel**: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$

Q17: A 12.0V power supply is connected to a 200 Ω resistor and another component of resistance 50Ω . Calculate the potential difference across each resistor, and the current flowing through the circuit. How many coulombs of charge will be drawn from the power supply in 5 minutes? Now repeat the question with both resistors in parallel.

Q18: 1.23A of current are drawn through an electrical heater. It supplies 1200W of heat with an energy efficiency of 80%. If the heater is a coil of wire that glows when current passes through it, what is its resistance?

Q19: Calculate the electrical resistance of a 100km aluminium power cable of radius 1.50cm.

Q20: A copper wire of diameter 2.00mm has a resistance of 0.01 Ω . How long is the wire?

**'Right hand thumbs up rule'** for **magnetic field** (fingers) due to a **current** (thumb)

**Right hand grip rule for solenoids** (fingers represent current, thumb is north pole)

**Fleming's Left hand motor rule:** (Thumb: **Motion**, First finger: **magnetic Field**, Index finger: **Current**)

**Faraday's law of induction:** ***Voltage*** *induced is proportional to the* ***rate of change of magnetic flux linked.***

**Right hand generator rule:** (Thumb: **Motion**, First finger: **magnetic Field**, Index finger: **Current**)

Q21: Sketch the magnetic field lines around a solenoid, and describe how the diagram represents how magnetic field strength varies with distance from the solenoid. How could you make the field stronger?

Q22: Draw a diagram of an *electromagnetic relay*, and describe in bullet points how it works

Q23: Explain via a diagram how a strip of aluminium held between the poles of a magnet can be made to oscillate when an AC current is passed through the aluminium.

Q24: A non-magnetic steel wheel of a train passes between the poles of an electromagnet. Explain in bullet points how the wheel can be stopped rotating when the electromagnet is turned on. Explain what happens to the kinetic energy of the wheel.

**Transformers:** $\frac{V_2}{V_1} = \frac{N_2}{N_1}$ $\frac{I_2}{I_1} = \frac{N_1}{N_2}$ $V_1, I_1$ Voltage, current in primary coil, $V_2, I_2$ voltage, current in secondary coil, $N_1, N_2$ number of turns in primary, secondary coils.

Q25: Electricity is AC, RMS 11kV in an overhead power line, and AC RMS 230V from a domestic mains plug socket.

(i) By means of a voltage vs time sketch graph, explain what “AC” and “RMS 230V” means.

(ii) In the step-down transformer between the power line and the sub-system which is connected to your house, the number of secondary coils is 50. How many primary coils must there be?

(iii) An average house requires a maximum electrical power input of about 9200W. If this is supplied by 230V AC, determine the corresponding current in A.

(iv) If 321 homes are supplied by a single 11kV power line, determine the maximum current drawn though the power line.

## THERMAL PHYSICS

**Ideal gas law:** $pV = nRT$

$p$ pressure, $V$ volume, $n$ number of moles of gas, molar gas constant $R$ = 8.314 $Jmol^{-1}K^{-1}$, $T$ absolute temperature (in Kelvin). $V \propto T$ **Charles' Law** $p \propto \frac{1}{V}$ **Boyle's Law**

Q26: An empty plastic drinks bottle of volume 500$cm^3$ is open at ground level, where the pressure is 101kPa (about 1 atmosphere) and the temperature is 5$^oC$. It is taken on a ski lift to 3500m, where the pressure drops to 72kPa and the temperature is -20$^oC$. The bottle is then sealed before taken back down on the lift to ground level. What is the volume of the crushed bottle, assuming the sides can withstand very little pressure difference.

$\Delta E = mc\Delta T$ Energy $\Delta E$ required to raise the temperature of a mass $m$ by $\Delta T$ where $c$ is the specific heat capacity (i.e. heat capacity per kilogram of thermal mass). $\Delta E = mL_{vap}$ **:** Energy $\Delta E$ required to convert $m$ kg of liquid to gas, at the boiling temperature of the liquid. $L_{vap}$ is the specific latent heat of vaporisation. $\Delta E = mL_{fus}$ **:** Energy $\Delta E$ required to convert $m$ kg of solid to liquid, at the freezing temperature of the liquid. $L_{fus}$ is the specific latent heat of fusion.

Q27: Water has a specific heat capacity of about 4200J/kg/K. If a 2kW kettle is 100% efficient, calculate how much time it will take to raise 1.23kg of water from 10$^oC$ to 100$^oC$.

Q28: Gold has a specific latent heat of fusion of 62.8kJ/kg and a specific heat capacity of 129J/kg/K. In the first series of *Game of Thrones*, about 2.0kg of molten gold is poured onto the head of Viserys Targaryen. Assuming the gold is initially at 1200$^oC$ and ends up solid at 20$^oC$, calculate the total thermal energy transferred. Gold has a melting point of 1063$^oC$. Try not to think about where the heat went!

Temperature conversions: **Fahrenheit** to **Celsius** to **Kelvin**: $T_K = T_C + 273.15$, $T_F = \frac{9}{5}T_C + 32$

Q29: The temperature at the US Antarctic base McMurdo station varies from -18$^oF$ to 33$^oF$. What is this range in Celsius?

**Pressure of a column of fluid:** $p = \rho gh$. $p$ pressure**,** $\rho$ fluid density**,** $g$ gravitational acceleration**,** $h$ height of fluid column.

Q30: Seawater has a density of about 1029$kg/m^3$. If atmospheric pressure is 101kPa, calculate how deep you must dive to gain an extra atmosphere of pressure.

Q31: An elephant seal dives to a depth of about 1,550m and blows a bubble of radius $r$. By what factor does the bubble radius increase as the bubble rises to the surface? Assume the water temperature is the same.

Q32: How many mm of a column of mercury corresponds to 10kPa change of pressure? Mercury density is 13,593$kg/m^3$.

## WAVES & OPTICS

**Angle of incidence = angle of reflection**: $\theta_i = \theta_r$ : **Snell's law of refraction**: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **.**

This is an electromagnetic wave special case of: $\sin\theta / \text{wave speed}$ **= constant.**

$n$ = refractive index (**speed of light in a vacuum / speed of light in a medium**). Angles $\theta$ are measured from the **normal** to the reflecting surface. **Total internal reflection** at glass : air interface i.e. no **refraction** if $n_{glass} \sin\theta_c = n_{air} \sin 90^o$ . This is the *critical angle*

Q33: Sunlight strikes the surface of a lake at 50$^o$ to the surface normal. It passes through 5.0m of water (refractive index 1.33) and then through a 10cm thick glass window of a Secret Underwater Base. What angle from the normal of the glass does the light ray travel? The refractive index of glass is 1.52.

Q34: Calculate (i) the critical angle for light travelling between glass and lake water (ii) glass and air.

Q35: White light travels through the top of a triangular (glass) prism such that the red wavelengths are refracted slightly above the horizontal, and green and blues slightly below. Sketch how the different colours *disperse* as they emerge from the prism (into air).

Q36: Draw a diagram to show how light can travel without much *attenuation* in an optic fibre.

**Wave speed:** $c = f\lambda$ **.** $c$ speed , $f$ frequency, $\lambda$ wavelength. **Frequency:** $f = \frac{1}{T}$ . $f$ frequency, $T$ time period of oscillation. **Speed of light in a vacuum:** 2.998 $\times$ 10$^8$ ms$^{-1}$. **Speed of sound in air** (20$^o$C): 344 ms$^{-1}$
**Speed of sound in water:** 1482 ms$^{-1}$

Q37: The musical note A (440Hz) is played by a flute. Calculate the wavelength in (i) air and (ii) water.

Q38: An ultrasonic pulse from a Dolphin in water has a wavelength of 1.23cm.
Calculate the frequency in Hz and period in s.

Q39: A water wave travelling at 10m/s in deep water strikes the normal to a reef at 30$^o$. Over the reef the wave speed drops to 6m/s. If the wavelength of the wave over the reef is 16m, calculate the wavelength in deep water. Also calculate the angle of refraction of the wave as it passes over the reef.

Q40: The waves then pass through a aperture of gap 16m between large rocks. Sketch what will happen to the wavefronts beyond the gap. Assume the water is the same depth as before the rocks.

**Thin lens Formula:** $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ **.** $u$ object distance , $v$ image distance, $f$ focal length of a lens

Q41: A luminous object of height 10cm is placed 30cm behind a thin lens of focal length 5cm. How far away from the lens will the image be, and what will be its height? Draw a diagram as well as use the thin lens formula while performing your calculation.

Q42: By means of a ray diagram, explain how a thin lens can be used as a magnifying glass when an object (use a stick and circular pinhead) is placed within the focal length of the lens.

## NUCLEAR PHYSICS

The number of decays of a radioactive element per second (**'activity'**) is **proportional** to the **number of radioactive atoms that have not yet decayed**

$T_{\frac{1}{2}}$ **half life**. The time taken for half of the number of radioactive elements in a sample to decay.

The graph of the **activity** vs **time** is an **exponential decay.**

**Alpha decay:** $^{Z+N}_{Z}\text{X} \rightarrow {}^{Z+N-4}_{Z-2}\text{Y} + \alpha$ $\quad ^{229}_{90}\text{Th} \rightarrow {}^{225}_{88}\text{Ra} + \alpha$ **Atomic number** (Z) *reduces* by 2. **Mass number** (A) *reduces* by 4

Kinetic energy of alpha particle (a Helium nucleus) is approximately 5MeV. (100,000 $\times$ ionization energy for an air molecule).

**Beta decay:** $^{Z+N}_{Z}\text{X} \rightarrow {}^{Z+N}_{Z+1}\text{Y} + \beta$ Atomic number (Z) *increases* by 1. Mass number (A) *stays the same*

$^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + \beta$

Kinetic energy of beta particles (high energy electrons) are 0.01 to 10MeV, i.e. a *spectrum* of energies. [1MeV = 1.60 x $10^{-13}$ J]

**Gamma rays:** Very high energy photons, i.e. electromagnetic waves of *very* high frequency.
**Gamma** radiation is more **penetrating** than **beta**, which is more penetrating than **alpha**.

Q43: The isotope Iodine-123 has a half life of 13.22 hours, and a dosage of about 20 Mega-Becquerel is needed for thyroid gland imaging. If the activity of ingested Iodine-123 starts at 25MBq, calculate the dosage after 52.88 hours.

Q44: Cobalt-60 decays via a beta particle to Nickel-60. If the atomic number of Co is 27, write a decay equation for this process.

Q45: Plutonium (Pu) decays via emission of an alpha particle to U-236 (Uranium), which has 144 neutrons. Work out the mass and atomic number for the isotope of Plutonium and hence write a decay equation for this process.

Q46: List one practical each application for (i) alpha, (ii) beta and (iii) gamma radiation. Explain why each form of radiation is unique to the particular application i.e. the alpha and beta are not appropriate for the gamma application etc.

Q47: Use the information above about alpha particles to estimate the ionization energy (in eV) of air molecules.

Q48: Alpha and Beta particles can be distinguished by how they move in the vicinity of a magnetic field. Illustrate this difference using a diagram.

**Misc questions on energy generation**

1 kilo-watt-hour (kWh) is a standard unit of energy, and costs about £0.1.

Q49: My electricity bill for February 2019 was £48.90. How many kWh did I use? How many J of energy did I use? What was the average power use (in W) during this time? Why is the latter likely to be misleading?

Q50: According the Mackay's *Sustainable Energy Without the Hot Air*, the total energy consumption in the UK is about 125 kWh/p/d where p means 'person' and d means 'day.' If the UK population is about 70million, and a typical wind turbine has a power output of about 2.5MW, calculate how many wind turbines need to be active to supply all the UK's power needs. (Currently there are about 7,050 turbines onshore and 1830 turbines offshore at the time of writing).