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| **Learning outcome** | **Done?** | **Lesson review** | **Revision** |
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| **Measurements and their errors** |  |  |  |  |  |  |  |
| 1 | Fundamental (base) units. |  |  |  |  |  |  |  |
| 2 | Use of mass, length, time, quantity of matter, temperature, electric current and their associated SI units. |  |  |  |  |  |  |  |
| 3 | SI units derived. |  |  |  |  |  |  |  |
| 4 | Knowledge and use of the SI prefixes, values and standard form. |  |  |  |  |  |  |  |
| 5 | Use the prefixes:T, G, M, k, c, m, μ, n, p, f, |  |  |  |  |  |  |  |
| 6 | Convert between different units of the same quantity, eg J and eV, J and kW h |  |  |  |  |  |  |  |
| 7 | Random and systematic errors. |  |  |  |  |  |  |  |
| 8 | Precision, repeatability, reproducibility, resolution and accuracy. |  |  |  |  |  |  |  |
| 9 | Uncertainty:Absolute, fractional and percentage uncertainties represent uncertainty in the final answer for a quantity. |  |  |  |  |  |  |  |
| 10 | Combination of absolute and percentage uncertainties. |  |  |  |  |  |  |  |
| 11 | Represent uncertainty in a data point on a graph using error bars. |  |  |  |  |  |  |  |
| 12 | Determine the uncertainties in the gradient and intercept of a straight-line graph. |  |  |  |  |  |  |  |
| 13 | Individual points on the graph may or may not have associated error bars. |  |  |  |  |  |  |  |
| 14 | Orders of magnitude. |  |  |  |  |  |  |  |
| 15 | Estimation of approximate values of physical quantities. |  |  |  |  |  |  |  |

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| **Particles and radiation** |  |  |  |  |  |  |  |
| 1 | Simple model of the atom, including the proton, neutron and electron. Charge and mass of the proton, neutron and electron in SI units and relative units. |  |  |  |  |  |  |  |
| 2 | Specific charge of the proton and the electron, and of nuclei and ions. |  |  |  |  |  |  |  |
| 3 | Proton number *Z*, nucleon number *A*, nuclide notation. |  |  |  |  |  |  |  |
| 4 | Be familiar with the $$notation. |  |  |  |  |  |  |  |
| 5 | Meaning of isotopes and the use of isotopic data. |  |  |  |  |  |  |  |
| 6 | The strong nuclear force; its role in keeping the nucleus stable; short-range attraction up to approximately 3 fm, very-short range repulsion closer than approximately 0.5 fm. |  |  |  |  |  |  |  |
| 7 | Unstable nuclei; alpha and beta decay. |  |  |  |  |  |  |  |
| 8 | Equations for alpha decay, β− decay including the need for the neutrino. |  |  |  |  |  |  |  |
| 9 | Know the existence of the neutrino was hypothesised to account for conservation of energy in beta decay. |  |  |  |  |  |  |  |
| 10 | For every type of particle, there is a corresponding antiparticle. |  |  |  |  |  |  |  |
| 11 | Comparison of particle and antiparticle masses, charge and rest energy in MeV. |  |  |  |  |  |  |  |
| 12 | Know that the positron, antiproton, antineutron and antineutrino are the antiparticles of the electron, proton, neutron and neutrino respectively. |  |  |  |  |  |  |  |
| 13 | Photon model of electromagnetic radiation, the Planck Constant:$$E=hf=\frac{hc}{λ}$$ |  |  |  |  |  |  |  |
| 14 | Knowledge of annihilation and pair production and the energies involved. |  |  |  |  |  |  |  |
| 15 | Four fundamental interactions: gravity, electromagnetic, weak nuclear, strong nuclear. (The strong nuclear force may be referred to as the strong interaction.) |  |  |  |  |  |  |  |
| 16 | Explain the concept of exchange particles to explain forces between elementary particles. |  |  |  |  |  |  |  |
| **Learning outcome** | **Done?** | **Lesson review** | **Revision** |
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| **Particles and radiation continued…** |  |  |  |  |  |  |  |
| 17 | The electromagnetic force; virtual photons as the exchange particle. |  |  |  |  |  |  |  |
| 18 | The weak interaction limited to β−and β+ decay, electron capture and electron–proton collisions; W+ and W− as the exchange particles. |  |  |  |  |  |  |  |
| 19 | Simple diagrams to represent the above reactions or interactions in terms of incoming and outgoing particles and exchange particles. |  |  |  |  |  |  |  |
| 20 | Hadrons are subject to the strong interaction.The two classes of hadrons:* baryons (proton, neutron) and antibaryons (antiproton and antineutron)
* mesons (pion, kaon).
 |  |  |  |  |  |  |  |
| 21 | Baryon number as a quantum number. |  |  |  |  |  |  |  |
| 22 | Conservation of baryon number. |  |  |  |  |  |  |  |
| 23 | The proton is the only stable baryon into which other baryons eventually decay. |  |  |  |  |  |  |  |
| 24 | The pion as the exchange particle of the strong nuclear force. |  |  |  |  |  |  |  |
| 25 | The kaon as a particle that can decay into pions. |  |  |  |  |  |  |  |
| 26 | Leptons are subject to the weak interaction. |  |  |  |  |  |  |  |
| 27 | Leptons: electron, muon, neutrino (electron and muon types only) and their antiparticles. |  |  |  |  |  |  |  |
| 28 | Lepton number as a quantum number; conservation of lepton number for muon leptons and for electron leptons. |  |  |  |  |  |  |  |
| 29 | The muon as a particle that decays into an electron. |  |  |  |  |  |  |  |
| 30 | Strange particles as particles that are produced through the strong interaction and decay through the weak interaction(eg kaons). |  |  |  |  |  |  |  |
| 31 | Strangeness (symbol s) as a quantum number to reflect the fact that strange particles are always created in pairs. |  |  |  |  |  |  |  |
| 32 | Conservation of strangeness in strong interactions. |  |  |  |  |  |  |  |
| 33 | Strangeness can change by 0, +1 or -1 in weak interactions. |  |  |  |  |  |  |  |
| **Learning outcome** | **Done?** | **Lesson review** | **Revision** |
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| **Particles and radiation continued…** |  |  |  |  |  |  |  |
| 34 | Appreciation that particle physics relies on the collaborative efforts of large teams of scientists and engineers to validate new knowledge. |  |  |  |  |  |  |  |
| 35 | Properties of quarks and antiquarks: charge, baryon number and strangeness. |  |  |  |  |  |  |  |
| 36 | Combinations of quarks and antiquarks required for baryons (proton and neutron only), antibaryons (antiproton and antineutron only) and mesons (pion and kaon only). |  |  |  |  |  |  |  |
| 37 | Knowledge of up (u), down (d) and strange (s) quarks and their antiquarks. |  |  |  |  |  |  |  |
| 38 | Know the decay of the neutron. |  |  |  |  |  |  |  |
| 39 | Change of quark character in β− and in β+ decay. |  |  |  |  |  |  |  |
| 40 | Application of the conservation laws for charge, baryon number, lepton number and strangeness to particle interactions. (The necessary data will be provided in questions for particles outside those specified). |  |  |  |  |  |  |  |
| 41 | Recognise that energy and momentum are conserved in interactions. |  |  |  |  |  |  |  |
| 42 | Threshold frequency; photon explanation of threshold frequency. |  |  |  |  |  |  |  |
| 43 | Work function $ϕ$, stopping potential. |  |  |  |  |  |  |  |
| 44 | Photoelectric equation:$$hf=ϕ+E\_{K(max)}$$ |  |  |  |  |  |  |  |
| 45 | *E*k (max) is the maximum kinetic energy of the photoelectrons |  |  |  |  |  |  |  |
| 46 | Ionisation and excitation; understanding of ionisation and excitation in the fluorescent tube. |  |  |  |  |  |  |  |
| 47 | The electron volt. |  |  |  |  |  |  |  |
| 48 | Convert eV into J and vice versa. |  |  |  |  |  |  |  |
| 49 | Line spectra (eg of atomic hydrogen) as evidence for transitions between discrete energy levels in atoms.$$hf=E\_{1}-E\_{2}$$In questions, energy levels may be quoted in J or eV. |  |  |  |  |  |  |  |
| **Learning outcome** | **Done?** | **Lesson review** | **Revision** |
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| **Particles and radiation continued…** |  |  |  |  |  |  |  |
| 50 | Know that electron diffraction suggests thatparticles possess wave properties and the photoelectric effect suggests that electromagnetic waves have a particulate nature |  |  |  |  |  |  |  |
| 51 | de Broglie wavelength $$λ=\frac{h}{mv}$$where *mv* is the momentum. |  |  |  |  |  |  |  |
| 52 | Explain how and why the amount of diffraction changes when the momentum of the particle is changed. |  |  |  |  |  |  |  |
| 53 | Appreciation of how knowledge and understanding of the nature of matter changes over time. |  |  |  |  |  |  |  |
| 54 | Appreciation that such changes need to be evaluated through peer review and validated by the scientific community. |  |  |  |  |  |  |  |

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| **Mechanics and materials** |  |  |  |  |  |  |  |
| 1 | Nature of scalars and vectors.Examples should include:velocity/speed, mass, force/weight, acceleration, displacement/distance. |  |  |  |  |  |  |  |
| 2 | Addition of vectors by calculation or scale drawing. Calculations will be limited to two vectors at right angles. Scale drawings may involve vectors at angles other than 90°. |  |  |  |  |  |  |  |
| 3 | Resolution of vectors into two components at right angles to each other.Examples should include components of forces along and perpendicular to an inclined plane.(Problems may be solved either by the use of resolved forces or the use of a closed triangle.) |  |  |  |  |  |  |  |
| 4 | Conditions for equilibrium for two or three coplanar forces acting at a point. Appreciation of the meaning ofequilibrium in the context of an object at rest or moving with constant velocity. |  |  |  |  |  |  |  |
| 5 | Moment of a force about a point. |  |  |  |  |  |  |  |
| 6 | Moment defined as *force × perpendicular distance from the point to the line of action of the force*. |  |  |  |  |  |  |  |
| 7 | Couple as a pair of equal and opposite coplanar forces. |  |  |  |  |  |  |  |
| 8 | Moment of couple defined as *force × perpendicular distance between the lines of action of the forces*. |  |  |  |  |  |  |  |
| 9 | Principle of moments. |  |  |  |  |  |  |  |
| 10 | Centre of mass. |  |  |  |  |  |  |  |
| 11 | Knowledge that the position of the centre of mass of uniform regular solid is at its centre. |  |  |  |  |  |  |  |
| 12 | Displacement, speed, velocity, acceleration.$$v=\frac{∆s}{∆t}$$$$a=\frac{∆v}{∆t}$$Calculations may include average and instantaneous speeds and velocities. |  |  |  |  |  |  |  |
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| **Mechanics and materials continued…** |  |  |  |  |  |  |  |
| 13 | Representation by graphical methods of uniform and non-uniform acceleration. |  |  |  |  |  |  |  |
| 14 | Significance of areas of velocity–time and acceleration–time graphs and gradients of displacement–time and velocity–time graphs for uniform and non-uniform acceleration eg. graphs for motion of bouncing ball. |  |  |  |  |  |  |  |
| 15 | Equations for uniform acceleration:$$v=u+at$$$$s=\left(\frac{u+v}{2}\right)t$$$$s=ut+\frac{at^{2}}{2}$$$$v^{2}=u^{2}+2as$$Acceleration due to gravity, *g*. |  |  |  |  |  |  |  |
| 16 | Independent effect of motion in horizontal and vertical directions of a uniform gravitational field. (Problems will be solvable using the equations of uniform acceleration). |  |  |  |  |  |  |  |
| 17 | Qualitative treatment of friction. |  |  |  |  |  |  |  |
| 18 | Qualitative treatment of lift and drag forces. |  |  |  |  |  |  |  |
| 19 | Terminal speed. |  |  |  |  |  |  |  |
| 20 | Knowledge that air resistance increases with speed. |  |  |  |  |  |  |  |
| 21 | Qualitative understanding of the effect of air resistance on the trajectory of a projectile and on the factors that affect the maximum speed of a vehicle. |  |  |  |  |  |  |  |
| 22 | Knowledge and application of the three laws of motion in appropriate situations. |  |  |  |  |  |  |  |
| 23 | *F* = *ma* for situations where the mass is constant. |  |  |  |  |  |  |  |
| 24 | $$momentum=mass x velocity $$ |  |  |  |  |  |  |  |
| 25 | Conservation of linear momentum. |  |  |  |  |  |  |  |

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| **Mechanics and materials continued…** |  |  |  |  |  |  |  |
| 26 | Principle applied quantitatively to problems in one dimension. |  |  |  |  |  |  |  |
| 27 | Force as the rate of change of momentum$$F=\frac{∆(mv)}{t}$$ |  |  |  |  |  |  |  |
| 28 | Impulse = change in momentum |  |  |  |  |  |  |  |
| 29 | $$F∆t=∆\left(mv\right)$$where *F* is constant. |  |  |  |  |  |  |  |
| 30 | Significance of the area under a force–time graph. |  |  |  |  |  |  |  |
| 31 | Quantitative questions on forces that vary with time. Impact forces are related to contact times (eg kicking a football, crumple zones, packaging). |  |  |  |  |  |  |  |
| 32 | Elastic and inelastic collisions; explosions. |  |  |  |  |  |  |  |
| 33 | Appreciation of momentum conservation issues in the context of ethical transport design. |  |  |  |  |  |  |  |
| 34 | Energy transferred$$W=Fscosθ$$ |  |  |  |  |  |  |  |
| 35 | *rate of doing work* = *rate of energy transfer*$$P=\frac{∆W}{∆t}=Fv$$ |  |  |  |  |  |  |  |
| 36 | Quantitative questions on variable forces. |  |  |  |  |  |  |  |
| 3738 | Significance of the area under a force–displacement graph. |  |  |  |  |  |  |  |
| 39 | $$efficiency=\frac{useful output power}{input power}$$ |  |  |  |  |  |  |  |
| 40 | Efficiency can be expressed as a percentage. |  |  |  |  |  |  |  |
| 41 | Principle of conservation of energy. |  |  |  |  |  |  |  |
| 42 | $$∆E\_{p}=mg∆h$$$$E\_{K}=\frac{1}{2}mv^{2}$$ |  |  |  |  |  |  |  |
| 43 | Quantitative and qualitative application of energy conservation to examples involving gravitational potential energy, kinetic energy, and work done against resistive forces. |  |  |  |  |  |  |  |

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| **Materials** |  |  |  |  |  |  |  |
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