Spec reference	Spec point	Extra details
5.1.1 Temperature	(a) thermal equilibrium (b) absolute scale of temperature (i.e. the thermodynamic scale) that does not depend on property of any particular substance. (c) temperature measurements both in degrees Celsius (°C) and in kelvin (K) (d) T (K) ≈ T (°C) + 273	The rate of transfer of heat from a body to the surroundings equals the rate of heat received – occurs when the temperatures are the same. T α KE of particles on the thermodynamic scale.
5.1.2 Solid, liquid and gas	(a) solids, liquids and gases in terms of the spacing, ordering and motion of atoms or molecules. (b) simple kinetic model for solids, liquids and gases. (c) Brownian motion in terms of the kinetic model of matter and a simple demonstration using smoke particles suspended in air, (d) internal energy as the sum of the random distribution of kinetic and potential energies associated with the molecules of a system (e) absolute zero (0 K) as the lowest limit for temperature; the temperature at which a substance has minimum internal energy	Descriptions. What can be deduced about the motion of invisible particles from the observations of the visible particles' motion. KE depends on temperature. PE depends on state changes undergone.

	(f) increase in the internal energy of a body as its temperature rises (g) changes in the internal energy of a substance during change of phase; constant temperature during change of phase.	Description (via temperature against heat graph) of how internal energy changes as an object is heated – KE increases as temperature increases, PE increases during melting/boiling.
5.1.3 Thermal properties of materials	(a) specific heat capacity of a substance; the equation E = mCΔΘ. Estimating specific heat capacity, using method of mixture. (b) (i) an electrical experiment to determine the specific heat capacity of a metal or a liquid (ii) techniques and procedures used for an electrical method to determine the specific heat capacity of a metal block and a liquid (c) specific latent heat of fusion and specific latent heat of vaporisation; E = mL (d) (i) an electrical experiment to determine the specific latent heat of fusion and vaporisation (ii) techniques and procedures used for an electrical method to determine the specific latent heat of a solid and a liquid.	Placing a piece of metal of know mass, initial temperature and SHC into a known mass of water and measuring the temperature rise of the water when they equilibrate.

5.1.4 Ideal gases	(a) amount of substance in moles; Avogadro constant N_A equals 6.02 × 10^{23} mol^{-1} (b) model of kinetic theory of gases assumptions for the model:	• large number of molecules in random, rapid motion particles (atoms or molecules) • occupy negligible volume compared to the volume of gas • all collisions are perfectly elastic • and the time of the collisions is negligible compared to the time between collisions • negligible forces between particles except during collision.
	(c) pressure in terms of this model. Explanation of pressure in terms of Newtonian theory.	Relate to Newton's 2nd and 3rd laws – Describe why pressure changes with temperature at a fixed volume or changing volumes at a fixed temperature.
	(d) (i) the equation of state of an ideal gas pV = nRT, where n is the number of moles	You don't need to know the derivation of this equation but should know how to calculate the Net force exerted by one particle undergoing elastic collisions in a cubic box.
	(ii) techniques and procedures used to investigate PV = constant (Boyle's law) and T/P = constant	State Boyle's law. PAGs – Boyle's law including AQA method and the Bourdon Pressure gauge apparatus. Charles' law in order to

	(iii) an estimation of absolute zero using variation of gas temperature with pressure. e) the equation $$pV = \frac{1}{3}Nm\overline{c^2}$$ where N is the number of particles (atoms or molecules) and $\overline{c^2}$ is the mean square speed Derivation of this equation is not required. (f) root mean square (r.m.s.) speed; mean square speed Learners should know about the general characteristics of the Maxwell-Boltzmann distribution. (g) the Boltzmann constant; $$k = \frac{R}{N_A}$$ **(h)** $pV = NkT$; $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ (i) internal energy of an ideal gas.	extrapolate the graph until y=0 to estimate absolute zero. Defining the idea of absolute zero, a gas has zero pressure and zero volume. Calculations of $\overline{c^2}$ from data. How the distribution changes with temperature. How the distribution can explain certain phenomena, like why water evaporates below boiling point etc. Assumption that an ideal gas's internal energy is completely kinetic, and therefore proportional to its thermodynamic temperature, which is a good estimate for a gas well above its boiling point.
on5.2.1 Kinematics of	a) the radian as a measure of angle	Θ/rads = Arc length/radius

circular motion	(b) period and frequency of an object in circular motion (c) angular velocity $\omega,\ \omega = \frac{2\pi}{T}$ or $\omega = 2\pi f$	Units Rads^{-1}
5.2.2 Centripetal force	(a) a constant net force perpendicular to the velocity of an object causes it to travel in a circular path. (b) constant speed in a circle; $v = \omega r$ (c) centripetal acceleration; $a = \frac{v^2}{r}$; $a = \omega^2 r$ (d) (i) centripetal force; $F = \frac{mv^2}{r}$; $F = m\omega^2 r$ (ii) techniques and procedures used to investigate circular motion using a whirling bung.	Centripetal force is the resultant force that causes circular motion and is always directed towards the centre of the circle. Horizontal circles (conical) – strings and objects, banking planes, vehicles rounding corners. Vertical circles – normal reaction force, weight, apparent weightlessness. Possible 6-marker from descriptions.

5.3.1 Simple harmonic oscillations	(a) displacement, amplitude, period, frequency, angular frequency and phase difference	
	(b) angular frequency $\omega,\ \omega = \frac{2\pi}{T}$ or $\omega =$	SHM is circular motion in 1 dimension.
	(c) (i) simple harmonic motion; defining equation: $a = -\omega^2 x$	Define simple harmonic motion as motion where the acceleration is proportional to the displacement from the equilibrium position and is always directed towards it.
	(ii) techniques and procedures used to determine the period/frequency of simple harmonic oscillations.	In terms of $\Theta = \omega t = 2\pi f t$
	(d) solutions to the equation: $a = -\omega^2 x$ e.g. $x = A\cos\omega t$ or $x = A\sin\omega t$	Cosine function if t=0 occurs when at the amplitude position, sine function if t=0 occurs at the equilibrium position. NB: simple pendulum displays SHM at small angle displacements.
	(e) velocity $v = \pm\omega\sqrt{A^2 - x^2}$ hence $v_{max} = \omega$.	
	(f) the period of a simple harmonic oscillator is independent of its amplitude (isochronous oscillator)	PAG – Static and dynamic methods of measuring k.
	(g) graphical methods to relate the changes in displacement, velocity and acceleration during simple harmonic motion.	Graphical representation of displacement-time, velocity-time and acceleration-time, and their linking (via the gradient).

5.3.2 Energy of a simple harmonic oscillator	(a) interchange between kinetic and potential energy during simple harmonic motion (b) energy-displacement graphs for a simple harmonic oscillator	Discussion of interchange between kinetic and potential energies for oscillating systems. Parabola-shaped graphs.
5.3.3 Damping	(a) free and forced oscillations (b) (i) the effects of damping on an oscillatory system (ii) observe forced and damped oscillations for a range of systems (c) resonance; natural frequency (d) amplitude-driving frequency graphs for forced oscillators (e) practical examples of forced oscillations and resonance.	Free – object will oscillate at its natural frequency. Forced – will oscillate at the driver frequency. Light damping has no effect on the Time period of oscillation. Exponential decay of amplitude over time. Discussion of how work done against friction/drag leads to a loss in kinetic energy of the oscillating system. Resonance – when the driving frequency = the natural frequency, maximum energy transfer occurs (between the driver and oscillating system), and the oscillator has a maximum amplitude of oscillation. Graphical representation of how an oscillator responds to varying frequencies of forced oscillations. The effect of damping on that graph.

5.4.1 Point and spherical masses	(a) gravitational fields are due to objects having mass (b) modelling the mass of a spherical object as a point mass at its centre (c) gravitational field lines to map gravitational fields d) gravitational field strength; $g = \frac{F}{m}$. (e) the concept of gravitational fields as being one of a number of forms of field giving rise to a force.	Model of mass surrounded by gravitational field. e.g. Earth. Arrows represent the direction of force acting on any mass placed in the field. Gravitational Field strength – the force per unit mass at that point in the field. Electric and magnetic fields.
5.4.2 Newton's law of gravitation	(a) Newton's law of gravitation; $F = -\frac{GMm}{r^2}$ force between two point masses (b) gravitational field strength $g = -\frac{GM}{r^2}$ for a point mass (c) gravitational field strength is uniform close to the surface of the Earth and numerically equal to the acceleration of free fall.	This can be stated with all symbols defined. The minus sign is an indication of direction – in the opposite direction of the displacement and therefore the force is attractive.
5.4.3 Planetary motion	(a) Kepler's three laws of planetary motion (b) the centripetal force on a planet is provided by the gravitational force between it and the Sun	

	(c) the equation $T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$ (d) the relationship for Kepler's third law $T^2 \propto r^3$ applied to systems other than our solar system (e) geostationary orbit; uses of geostationary satellites.	Derive this equation from first principles using Newton's law of gravitation and the centripetal force equation and $v = 2\pi r/T$ where r = radius of the circle. T^2/r^3 = a constant Description – orbits the equator with time period of 24 hours, in the direction of the earth's spin. Telecommunications.
5.4.4 Gravitational potential and energy	(a) gravitational potential at a point as ***the work done in bringing unit mass from infinity to the point***; gravitational potential is zero at infinity (b) gravitational potential $V_g = -\frac{GM}{r}.$ at a distance r from a point mass M; changes in gravitational potential (c) force–distance graph for a point or spherical mass; work done is area under graph (d) gravitational potential energy $E = mV_g = -\frac{GMm}{r}$ at a distance r from a point mass M	The minus sign indicates a loss in gravitational potential (when coming from infinity) rather than a direction as this is a scalar quantity. Usage in calculations $\Delta GPE = m\Delta V_g$ Once again, calculations involving an interchange of KE and GPE.

	(e) escape velocity.	Equating the (positive value of) GPE at the surface of a planet to the KE required to escape and reach infinity.
5.5.1 Stars	(a) the terms planets, planetary satellites, comets, solar systems, galaxies and the universe HSW7 (b) formation of a star from interstellar dust and gas in terms of gravitational collapse, fusion of hydrogen into helium, radiation and gas pressure Learners are not expected to know the details of fusion in terms of Einstein's mass-energy equation. (c) evolution of a low-mass star like our Sun into a red giant and white dwarf; planetary nebula (d) characteristics of a white dwarf; electron degeneracy pressure; Chandrasekhar limit (e) evolution of a massive star into a red super giant and then either a neutron star or black hole; supernova (f) characteristics of a neutron star and a black hole HSW8 (g) Hertzsprung–Russell (HR) diagram as luminosity temperature plot; main sequence; red giants; super red giants; white dwarfs.	Fermi pressure, electron degeneracy. If Chandrasekhar limit of white dwarf (1.44M_S) is exceeded, electron degeneracy cannot prevent further collapse. Protons and electrons interact to form neutrons. Neutron degeneracy prevents further collapse – supernova. Neutron star - huge density, rotating very quickly. Black hole - infinite density, light cannot escape from its event horizon. Evolution of the sun on H-R diagram.

5.5.2 Electromagnetic radiation from stars	(a) energy levels of electrons in isolated gas atoms (b) the idea that energy levels have negative values (c) emission spectral lines from hot gases in terms of emission of photons and transition of electrons between discrete energy levels (d) the equations $hf = \Delta E$ and $\frac{hc}{\lambda} = \Delta E$ (e) different atoms have different spectral lines which can be used to identify elements within stars (f) continuous spectrum, emission line spectrum and absorption line spectrum (g) transmission diffraction grating used to determine the wavelength of light (h) the condition for maxima $d \sin\theta = n\lambda$, where d is the grating spacing (i) use of Wien's displacement law $\lambda_{max} \propto \frac{1}{T}$ to estimate the peak surface temperature (of a star)	Ground state – lowest energy state an electron can exist in. Represents the energy required by an electron to leave the atom. Drawing Arrows to represent energy transitions for excitation and de-excitation. On de-excitation, Photons emitted where $\Delta E = E_1 - E_2$ How an absorption spectrum is set up. Definitions of each type of spectrum. For the nth maximum, ripples from adjacent slits arrive in phase with a path difference of $n\lambda$ PAG d/m = 1/number of lines metre^{-1} Target of ratios questions

	(j) luminosity L of a star; Stefan's Law where σ is the Stefan constant $L = 4\pi r^2 \sigma T^4$ (k) use of Wien's displacement law and Stefan's law to estimate the radius of a star.	Luminosity as the rate of emission of Black Body radiation measured in Watts. Intensity of radiation from a luminous source (star): Intensity = Luminosity/$4\pi r^2$ Where r = the distance from the star and hence the denominator is the area of an imagined sphere where the intensity is the same at all points.
5.5.3 Cosmology	(a) distances measured in astronomical unit (AU), light-year (ly) and parsec (pc) (b) stellar parallax; distances the parsec (pc) (c) the equation 1/p = d where p is the parallax in seconds of arc and d is the distance in parsec (d) the Cosmological principle; universe is homogeneous, isotropic and the laws of physics are universal (e) Doppler effect; Doppler shift of electromagnetic radiation (f) Doppler equation $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for a source of electromagnetic radiation moving relative to an observer,	 Definition of the parsec as the distance to a star where an arc length of 1AU subtends an angle of 1 second of arc. Homogenous: uniform density Isotropic: Same in all directions. Red shift and blue shift.

	(g) Hubble's law; $v \approx H_0 d$ for receding galaxies, where H_0 is the Hubble constant	v α d for a galaxies H_0 is a measure of the rate of expansion of the universe.
	(h) model of an expanding universe supported by galactic red shift (i) Hubble constant H_0 in both $kms^{-1}Mpc^{-1}$ and s^{-1} units	Conversion between the units.
	(j) the Big Bang theory (k) experimental evidence for the Big Bang theory from microwave background radiation at a temperature of 2.7 K The development and acceptance of Big Bang theory by the scientific community.	Outline of the evidence – Hubble's law, cosmic microwave background radiation, excessive amounts of Helium in the universe.
	(l) the idea that the Big Bang gave rise to the expansion of space-time	
	(m) estimation for the age of the universe; $t \approx H_0^{-1}$	
	(n) evolution of the universe after the Big Bang to the present	Logic $1/H_0 = v/d = t$
	(o) current ideas; universe is made up of dark energy, dark matter, and a small percentage of ordinary matter	Description of the main events in chronological order of the Big Bang from singularity, inflationary period to the present-day. Evidence for dark matter and dark energy.