IB Physics Notes, Links, and Syllabus content

Written by JCA
Physics Diploma Programme, First examinations 2009

Core SL

Students at SL are required to study any two options from A-G. The duration of each option is 15 hours.
Students at HL are required to study any two options from E-J. The duration of each option is 22 hours.

Section one – General Physics Links

Link	Comment
http://www.hockerillstudents.com/	My webpages
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html	Georgia state university – great site
http://www.saburchill.com/physics/physics.html	Open door IB physics **David Hoult**
http://www.physicsforums.com/	
http://www.revision-notes.co.uk/IB/Physics/index.html	
http://sites.google.com/site/ibphysicsstuff2/ibphysicsnotes	Search database for general topics
http://www.physics.org/	Instisute of Physics
www.physics-online.com	
http://www.ngsir.netfirms.com/	**Lots of applets to explore**
http://www.lon-capa.org/~mmp/applist/applets.htm	Another collection of applets
http://dev.physicslab.org/Default.aspx	Mainland's online physics program, PhysicsLAB™!

http://www.katsokos.com/PhySolutions.php	Solutions to text book questions
http://physics.nayland.school.nz	
http://www.falstad.com/mathphysics.html	Very good applets and simulations
http://www.khanacademy.org/science/physics	Video library
http://rcnuwc.org/ibphysics/ http://www.physics-inthinking.co.uk/ http://www.physics-inthinking.co.uk/multiple-choice-tests/wave-properties.htm	Chris Hamper
http://phet.colorado.edu/	Lots of simulations
http://gradegorilla.com/international.php	Multiple choice questions for revision
http://tsgphysics.mit.edu/front/	MIT Physics Technical services group, demonstrations etc.

Section two – Syllabus details with notes

Topic 1: Physics and physical measurement (5 hours)

1.1 The realm of physics

<table>
<tr><th></th><th>Assessment statement</th><th>Obj</th><th>Teacher’s notes</th></tr>
<tr><td colspan="4">Range of magnitudes of quantities in our universe</td></tr>
<tr><td>1.1.1</td><td>State and compare quantities to the nearest order of magnitude.</td><td>3</td><td></td></tr>
<tr><td>1.1.2</td><td>State the ranges of magnitude of distances, masses and times that occur in the universe, from smallest to greatest.
<table>
<tr><td>Distances</td><td>(metres)</td><td></td><td></td></tr>
<tr><td>10^{-15} (1 fm) Proton</td><td>10^{-10} Atom</td><td>10^{21} Milky way</td><td>10^{25} Universe</td></tr>
<tr><td>Masses</td><td>(kg)</td><td></td><td></td></tr>
<tr><td>10^{-30} Electron</td><td>10^{-27} Proton</td><td>10^{30} Sun</td><td>10^{50} Universe</td></tr>
<tr><td>Times</td><td>(s)</td><td></td><td></td></tr>
<tr><td>10^{-23} s →nucleus</td><td></td><td></td><td>10^{18}s Universe</td></tr>
</table></td><td>1</td><td>Distances: from 10^{-15} m to 10^{+25} m (sub-nuclear particles to extent of the visible universe).
Masses: from 10^{-30} kg to 10^{+50} kg (electron to mass of the universe).
Times: from 10^{-23} s to 10^{+18} s (passage of light across a nucleus to the age of the universe).</td></tr>
<tr><td>1.1.3</td><td>State ratios of quantities as differences of orders of magnitude.</td><td>1</td><td>For example, the ratio of the diameter of the hydrogen atom to its nucleus is about 10^5, or a difference of five orders of magnitude.</td></tr>
<tr><td>1.1.4</td><td>Estimate approximate values of everyday quantities to one or two significant figures and/or to the nearest order of magnitude.</td><td>2</td><td></td></tr>
</table>

1.2 Measurement and uncertainties

TOK: Data and its limitations is a fruitful area for discussion.

	Assessment statement	Obj	Teacher’s notes

The SI system of fundamental and derived units			
1.2.1	State the fundamental units in the SI system.	1	Students need to know the following: kilogram, metre, second, ampere, mole and kelvin.
1.2.2	Distinguish between fundamental and derived units and give examples of derived units.	2	
1.2.3	Convert between different units of quantities.	2	For example, J and kW h, J and eV, year and second, and between other systems and SI.
1.2.4	State units in the accepted SI format.	1	Students should use m s^{-2} not m/s^2 and m s^{-1} not m/s.
1.2.5	State values in scientific notation and in multiples of units with appropriate prefixes.	1	For example, use nanoseconds or gigajoules.
Uncertainty and error in measurement			
1.2.6	Describe and give examples of random and systematic errors.	2	Random errors in experimental measurements are caused by unknown and unpredictable changes in the experiment. These changes may occur in the measuring instruments or in the environmental conditions. Examples of causes of random errors are: • electronic noise in the circuit of an electrical instrument, • irregular changes in the heat loss rate from a solar collector due to changes in the wind. • Variations in the amount of friction when an obect is in motion Systematic errors in experimental observations can come from the measuring instruments. These may occur because: • there is something wrong with the instrument or its data handling system, or • because the instrument is wrongly used by the experimenter. Systematic errors can also come from deficiencies in an experimental method. They may occur because the experiment does not account for an environmental factor that influences a result for example: • ammeters, contacts and wires have resistance • heat loss is occuring Two types of systematic error can occur with instruments having a linear response: • Offset or zero setting error in which the instrument does not read zero when the quantity to be measured is zero. • Multiplier or scale factor error in which the instrument consistently reads changes in the quantity to be measured greater or less than the actual changes. Systematic errors also occur with non-linear instruments when the calibration of the instrument is not known correctly. The error could be in either direction.
1.2.7	Distinguish between precision and accuracy.	2	A measurement may have great precision yet may be inaccurate (for example, if the instrument has a zero offset error). Uncertainty values in a measurement often the same as the precision of the instrument. i.e. measuring temperature with a thermometer with a 1K precision the uncertainty is +/-1K. If there is a random inaccuracy then the uncertainty value should be increased. If there is a known systematic error then this can be compensated for.
1.2.8	Explain how the effects of random errors may be reduced.	3	Students should be aware that systematic errors are not reduced by repeating readings.
1.2.9	Calculate quantities and results of calculations to the appropriate number of significant figures.	2	The number of significant figures should reflect the precision of the value or of the input data to a calculation. Only a simple rule is required: for multiplication and division, the number of significant digits in a result should not exceed that of the least precise value upon which it depends. The number of significant figures in any answer should reflect the number of significant figures in the given data.
Uncertainties in calculated results			

1.2.10	State uncertainties as absolute, fractional and percentage uncertainties.	1	Absolute: Uncertainty is stated in the units of the measured variable. i.e. speed was 7.42 m/s +/- 0.6 m/s or speed was between 6.82 and 8.02 m/s Fractional: Speed was 7.42 m/s +/- 0.08 Percentage: Speed = 7.42 +/- 8%
1.2.11	Determine the uncertainties in results. Possible methods: 1) Min/Max: Establish reasonable estimates for errors in each measurement and calculate the minimum and maximum possible result. 2) Percentage error analysis: Establish percentage error on each measurement and process these percentages (usually add them) to get a final percentage error 3) Statistic spread analysis: For multiple readings a good error range is + or – two standard deviations of the range. As a rough guide this will be the range where 90% or more of the readings lie.	3	A simple approximate method rather than root mean squared calculations is sufficient to determine maximum uncertainties. For functions such as addition and subtraction, absolute uncertainties may be added. For multiplication, division and powers, percentage uncertainties may be added. For other functions (for example, trigonometric functions), the mean, highest and lowest possible answers may be calculated to obtain the uncertainty range. If one uncertainty is much larger than others, the approximate uncertainty in the calculated result may be taken as due to that quantity alone. NOTE: If there is a systematic error then the result will still be wrong!
Uncertainties in graphs **Aim 7:** This is an opportunity to show how spreadsheets are commonly used to calculate and draw error bars on graphs.			
1.2.12	Identify uncertainties as error bars in graphs.	2	
1.2.13	State random uncertainty as an uncertainty range (±) and represent it graphically as an "error bar".	1	Error bars need be considered only when the uncertainty in one or both of the plotted quantities is significant. Error bars will not be expected for trigonometric or logarithmic functions.
1.2.14	Determine the uncertainties in the gradient and intercepts of a straight-line graph.	3	Only a simple approach is needed. To determine the uncertainty in the gradient and intercept, error bars need only be added to the first and the last data points.

1.3 Vectors and scalars

This may be taught as a stand-alone topic or can be introduced when vectors are encountered in other topics such as 2.2, forces and dynamics, and 6.2, electric force and field.

	Assessment statement	Teacher's notes
1.3.1	Distinguish between vector and scalar quantities, and give examples of each.	A vector is represented in print by a bold italicized symbol, for example, ***F***.
1.3.2	Determine the sum or difference of two vectors by a graphical method.	Multiplication and division of vectors by scalars is also required.
1.3.3	Resolve vectors into perpendicular components along chosen axes.	For example, resolving parallel and perpendicular to an inclined plane.

Topic 2: Mechanics (17 hours)

Aim 7: This topic is a fruitful one for using spreadsheets and data logging in practical work as well as computer simulations in teaching various concepts.

A collection of applets
http://www.lon-capa.org/~mmp/applist/applets.htm

Galileo's breakthrough and then a game.
http://library.thinkquest.org/2779/History.html

GPE to KE
http://www.youtube.com/watch?v=L2mdAvdPhT4&feature=related

Gravitational potential
http://www.falstad.com/mathphysics.html
http://www.youtube.com/watch?v=HWUgj2xs0XQ

2.1 Kinematics

	Assessment statement	Teacher's notes
2.1.1	Define *displacement*, *velocity*, *speed* and *acceleration*.	Quantities should be identified as scalar or vector quantities. See sub-topic 1.3.
2.1.2	Explain the difference between instantaneous and average values of speed, velocity and acceleration.	
2.1.3	Outline the conditions under which the equations for uniformly accelerated motion may be applied.	
2.1.4	Identify the acceleration of a body falling in a vacuum near the Earth's surface with the acceleration *g* of free fall.	
2.1.5	Solve problems involving the equations of uniformly accelerated motion.	i.e. use the "suvat" group of equations correctly
2.1.6	Describe the effects of air resistance on falling objects.	Only qualitative descriptions are expected. Students should understand what is meant by terminal speed.
2.1.7	Draw and analyse distance–time graphs, displacement–time graphs, velocity–time graphs and acceleration–time graphs.	Students should be able to sketch and label these graphs for various situations. They should also be able to write descriptions of the motions represented by such graphs.
2.1.8	Calculate and interpret the gradients of displacement–time graphs and velocity–time graphs, and the areas under velocity–time graphs and acceleration–time graphs.	
2.1.9	Determine relative velocity in one and in two dimensions.	

2.2 Forces and dynamics

TOK: The development of the laws of motion raises interesting issues relating to correlation and cause and scientific theories.

	Assessment statement	Teacher's notes
2.2.1	Calculate the weight of a body using the expression $W = mg$.	
2.2.2	Identify the forces acting on an object and draw free-body diagrams representing the forces acting.	Each force should be labelled by name or given a commonly accepted symbol. Vectors should have lengths approximately proportional to their magnitudes. See sub-topic 1.3.
2.2.3	Determine the resultant force in different situations.	
2.2.4	State Newton's first law of motion.	
2.2.5	Describe examples of Newton's first law.	
2.2.6	State the condition for translational equilibrium.	
2.2.7	Solve problems involving translational	

	equilibrium.	
2.2.8	State Newton's second law of motion.	Students should be familiar with the law expressed as: .
2.2.9	Solve problems involving Newton's second law.	
2.2.10	Define *linear momentum* and *impulse*.	
2.2.11	Determine the impulse due to a time-varying force by interpreting a force–time graph.	
2.2.12	State the law of conservation of linear momentum.	
2.2.13	Solve problems involving momentum and impulse.	
2.2.14	State Newton's third law of motion.	
2.2.15	Discuss examples of Newton's third law.	Students should understand that when two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A.

2.3 Work, energy and power

	Assessment statement	Teacher's notes
2.3.1	Outline what is meant by work.	Students should be familiar with situations where the displacement is not in the same direction as the force.
2.3.2	Determine the work done by a non-constant force by interpreting a force–displacement graph.	A typical example would be calculating the work done in extending a spring. See 2.3.7.
2.3.3	Solve problems involving the work done by a force.	
2.3.4	Outline what is meant by kinetic energy.	
2.3.5	Outline what is meant by change in gravitational potential energy.	
2.3.6	State the principle of conservation of energy.	
2.3.7	List different forms of energy and describe examples of the transformation of energy from one form to another.	
2.3.8	Distinguish between elastic and inelastic collisions.	Students should be familiar with elastic and inelastic collisions and explosions. Knowledge of the coefficient of restitution is not required.
2.3.9	Define *power*.	
2.3.10	Define and apply the concept of *efficiency*.	
2.3.11	Solve problems involving momentum, work, energy and power.	Aeroplane questions Sledging question

2.4 Uniform circular motion

This topic links with sub-topics 6.3 and 9.4.

	Assessment statement	Teacher's notes
2.4.1	Draw a vector diagram to illustrate that the acceleration of a particle moving with constant speed in a circle is directed towards the centre of the circle.	
2.4.2	Apply the expression for centripetal acceleration.	

2.4.3	Identify the force producing circular motion in various situations.	Examples include gravitational force acting on the Moon and friction acting sideways on the tyres of a car turning a corner.
2.4.4	Solve problems involving circular motion.	Problems on banked motion (aircraft and vehicles going round banked tracks) will not be included

Topic 3: Thermal physics (7 hours)

3.1Thermal concepts

2 hours

	Assessment statement	Obj	Teacher's notes
3.1.1	State that temperature determines the direction of thermal energy transfer between two objects.	1	Students should be familiar with the concept of thermal equilibrium.
3.1.2	State the relation between the Kelvin and Celsius scales of temperature.	1	T/K = t/°C + 273 is sufficient.
3.1.3	State that the internal energy of a substance is the total potential energy and random kinetic energy of the molecules of the substance.	1	Students should know that the kinetic energy of the molecules arises from their random/translational/rotational motion and that the potential energy of the molecules arises from the forces between the molecules.
3.1.4	Explain and distinguish between the macroscopic concepts of temperature, internal energy and thermal energy (heat).	3	Students should understand that the term thermal energy refers to the non-mechanical transfer of energy between a system and its surroundings. In this respect it is just as incorrect to refer to the "thermal energy in a body" as it would be to refer to the "work in a body".
3.1.5	Define the *mole* and *molar mass*.	1	The amount of particles in 12g or Carbon-12. The mass of one mole of a substance. Therefore (moles(n) = mass / molar mass)
3.1.6	Define the *Avogadro constant*.	1	The number of particles in one mole of a substance (N_A) $N = n N_A$

3.2Thermal properties of matter

5 hours

	Assessment statement	Obj	Teacher's notes
Specific heat capacity, phase changes and latent heat			
3.2.1	Define *specific heat capacity* and *thermal capacity*.	1	
3.2.2	Solve problems involving specific heat capacities and thermal capacities.	3	
3.2.3	Explain the physical differences between the solid, liquid and gaseous phases in terms of molecular structure and particle motion.	3	Only a simple model is required. In a solid particles are held in fixed positions by intermolecular bonds and will vibrate with an average kinetic energy proportional to their temperature. In a liquid partciles can move past one another as some bonds have broken. In a gas the particles have obtained enough energy to break all the bonds and move freely average kinetic energy proportional to their temnperature
3.2.4	Describe and explain the process of phase changes in terms of molecular behaviour.	3	Students should be familiar with the terms melting, freezing, evaporating, boiling and condensing, and should be able to describe each in terms of the changes in molecular potential and random kinetic energies of molecules.
3.2.5	Explain in terms of molecular behaviour why temperature does not change during a phase change.	3	Breaking or making of bonds is a increase or decrease in potential energy of the particles not kinetic energy.

3.2.6	Distinguish between evaporation and boiling.	2	Evaporation occurs at the surface (of a liquid) and a any temperature. Boiling occurs throughout a liquid and at a specific temperature.
3.2.7	Define *specific latent heat*.	1	
3.2.8	Solve problems involving specific latent heats.	3	Problems may include specific heat calculations.
Kinetic model of an ideal gas **Aim 7:** There are many computer simulations of the behaviour of gases. **TOK:** The use of modelling in science may be introduced here.			
3.2.9	Define *pressure*.	1	
3.2.10	State the assumptions of the kinetic model of an ideal gas.	1	Point particles No intermolecular attraction Elastic collisions
3.2.11	State that temperature is a measure of the average random kinetic energy of the molecules of an ideal gas.	1	
3.2.12	Explain the macroscopic behaviour of an ideal gas in terms of a molecular model.	3	Only qualitative explanations are required. Students should, for example, be able to explain how a change in volume results in a change in the frequency of particle collisions with the container and how this relates to a change in pressure and/or temperature.

Topic 4: Oscillations and waves (10 hours)

Diffraction of waves

http://physics.bu.edu/~duffy/py106/Diffraction.html
http://physics.about.com/od/lightoptics/a/doubleslit.htm
http://www.tutorvista.com/content/physics/physics-iv/optics/youngs-double-slit-animation.php

4.1 Kinematics of simple harmonic motion (SHM)

2 hours

Aim 7: Many computer simulations of SHM are available.

	Assessment statement	Obj	Teacher's notes
4.1.1	Describe examples of oscillations.	2	SHM Presentation
4.1.2	Define the terms *displacement*, *amplitude*, *frequency*, *period* and *phase difference*.	1	The connection between frequency and period should be known.
4.1.3	Define *simple harmonic motion* (*SHM*) and state the defining equation as $a = -\omega^2 x$	1	Students are expected to understand the significance of the negative sign in the equation and to recall the connection between ω and T.
4.1.4	Solve problems using the defining equation for SHM.	3	
4.1.5	Apply the equations $v = v_0 \sin \omega t$, $v = v_0 \cos \omega t$, $v = \pm\omega\sqrt{(x_0^2 - x^2)}$, $x = x_0 \cos \omega t$ and $x = x_0 \sin \omega t$ as solutions to the defining equation for SHM.	2	
4.1.6	Solve problems, both graphically and by calculation, for acceleration, velocity and displacement during SHM.	3	

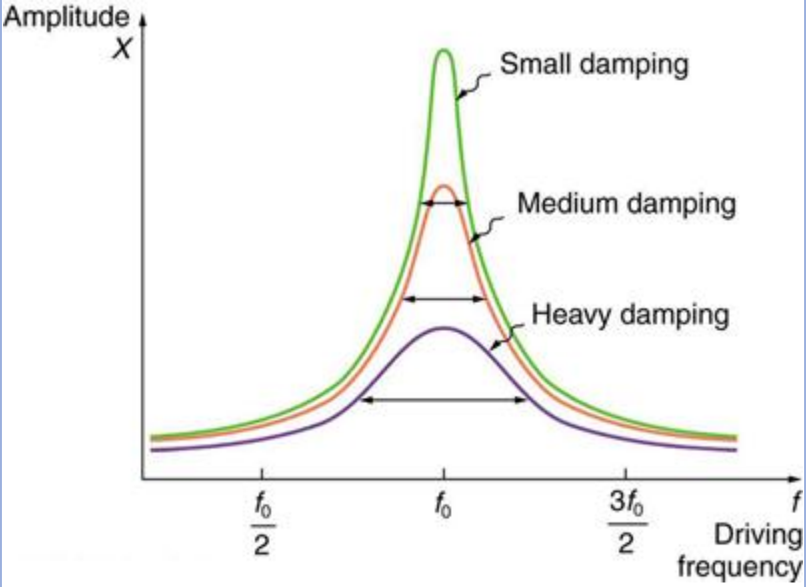
4.2 Energy changes during simple harmonic motion (SHM)

1 hour

	Assessment statement	Obj	Teacher's notes
4.2.1	Describe the interchange between kinetic energy and potential energy during SHM.	2	
4.2.2	Apply the expressions: $E_K = \frac{1}{2}m\omega^2\left(x_0{}^2 - x^2\right)$ for the kinetic energy of a particle undergoing SHM, $E_T = \frac{1}{2}m\omega^2 x_0{}^2$ for the total energy and $E_P = \frac{1}{2}m\omega^2 x^2$ for the potential energy.	2	
4.2.3	Solve problems, both graphically and by calculation, involving energy changes during SHM.	3	

4.3 Forced oscillations and resonance

3 hours

	Assessment statement	Obj	Teacher's notes
4.3.1	State what is meant by damping.	1	It is sufficient for students to know that damping involves a force that is always in the opposite direction to the direction of motion of the oscillating particle and that the force is a dissipative force.
4.3.2	Describe examples of damped oscillations.	2	Reference should be made to the degree of damping and the importance of critical damping. A detailed account of degrees of damping is not required.
4.3.3	State what is meant by natural frequency of vibration and forced oscillations.	1	Natural frequency is the frequency at whioch a system will oscillate if disturbed and then oscillates with no external force. A forces oscillation is when there is a varyinf force applies to a system that makes it oscillate.
4.3.4	Describe graphically the variation with forced frequency of the amplitude of vibration of an object close to its natural frequency of vibration.	2	Students should be able to describe qualitatively factors that affect the frequency response and sharpness of the curve. 
4.3.5	State what is meant by resonance.	1	Large amplitudes are caused when the frequency of the driving force acting on a system is equal to the natural frequency of the system.
4.3.6	Describe examples of resonance where the effect is useful and where it should be avoided.	2	Examples may include quartz oscillators, microwave generators and vibrations in machinery. In structures resonance needs to be avoided.

4.4 Wave characteristics

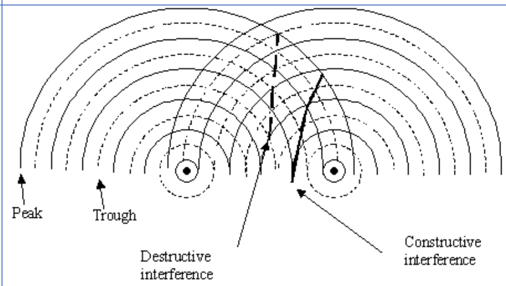
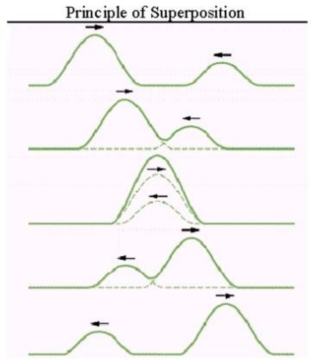
2 hours

	Assessment statement	Obj	Teacher's notes
4.4.1	Describe a wave pulse and a continuous progressive (travelling) wave.	2	Students should be able to distinguish between oscillations and wave motion, and appreciate that, in many examples, the oscillations of the particles are simple harmonic.
4.4.2	State that progressive (travelling) waves transfer energy.	1	Students should understand that there is no net motion of the medium through which the wave travels.
4.4.3	Describe and give examples of transverse and of longitudinal waves.	2	Students should describe the waves in terms of the direction of oscillation of particles in the wave relative to the direction of transfer of energy by the wave. Students should know that sound waves are longitudinal, that light waves are transverse and that transverse waves cannot be propagated in gases.
4.4.4	Describe waves in two dimensions, including the concepts of wavefronts and of rays.	2	
4.4.5	Describe the terms crest, trough, compression and rarefaction.	2	
4.4.6	Define the terms *displacement*, *amplitude*, *frequency*, *period*, *wavelength*, *wave speed* and *intensity*.	1	Students should know that intensity $\propto$ amplitude^2.
4.4.7	Draw and explain displacement–time graphs and displacement–position graphs for transverse and for longitudinal waves.	3	
4.4.8	Derive and apply the relationship between wave speed, wavelength and frequency.	3	
4.4.9	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 in the electromagnetic spectrum.	1	

4.5 Wave properties

2 hours

	Assessment statement	Obj	Teacher's notes
4.5.1	Describe the reflection and transmission of waves at a boundary between two media.	2	This should include the sketching of incident, reflected and transmitted waves.
4.5.2	State and apply Snell's law.	2	Students should be able to define refractive index in terms of the ratio of the speeds of the wave in the two media and also in terms of the angles of incidence and refraction.
4.5.3	Explain and discuss qualitatively the diffraction of waves at apertures and obstacles.	3	The effect of wavelength compared to aperture or obstacle dimensions should be discussed. Diffraction is the change in the directions and intensities of a group of waves after passing by an obstacle or through an aperture whose size is similar to the wavelength of the waves. The change in direction causes the waves to spread beyond the straight line directin from the source.
4.5.4	Describe examples of diffraction.	2	Light going through slits. Sound passing between buildings. Radio waves curvOing around hills.
4.5.5	State the principle of superposition and explain what is meant by constructive interference and by destructive interference.	3	Superposition principle: When more than one wave of the same type exist in the same place at the same time the displacements of the two waves add together. Constructive interference occurs where waves of the

			same type and frequency from more than one source meet and are in phase resulting in an addition of their amplitudes. Destructive interference occurs where waves of the same type and frequency from more than one source meet and are out of phase resulting in an addition of their amplitudes.
4.5.6	State and apply the conditions for constructive and for destructive interference in terms of path difference and phase difference. Constructive – Path difference = nλ Destrcutive – Path difference = (n+1/2)λ (n is an interger)	2	
4.5.7	Apply the principle of superposition to determine the resultant of two waves.	2	

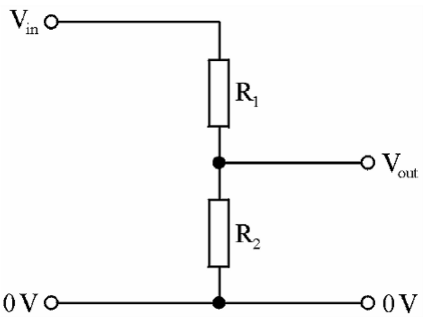
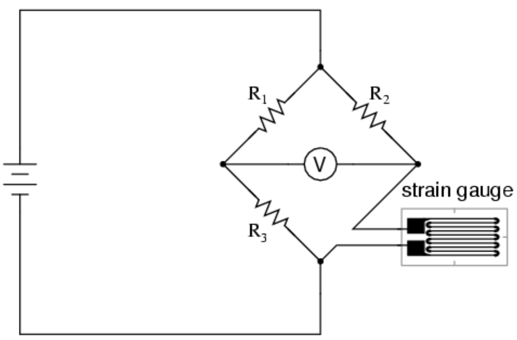
Topic 5: Electric currents (7 hours)

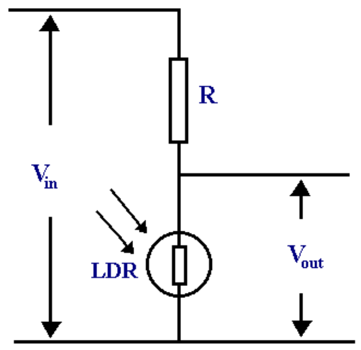
5.1 Electric potential difference, current and resistance

	Assessment statement		Teacher's notes
Electric potential difference			
5.1.1	Define *electric potential difference*.		
5.1.2	Determine the change in potential energy when a charge moves between two points at different potentials.		
5.1.3	Define the *electronvolt*.		
5.1.4	Solve problems involving electric potential difference.		
Electric current and resistance			
5.1.5	Define *electric current*.		It is sufficient for students to know that current is defined in terms of the force per unit length between parallel current-carrying conductors.
5.1.6	Define *resistance*.		Students should be aware that $R = V/I$ is a general definition of resistance. It is not a statement of Ohm's law. Students should understand what is meant by resistor.
5.1.7	Apply the equation for resistance in the form		

	$$R = \frac{\rho L}{A}$$ where ρ is the resistivity of the material of the resistor.		
5.1.8	State Ohm's law.		
5.1.9	Compare ohmic and non-ohmic behaviour.		For example, students should be able to draw the *I*–*V* characteristics of an ohmic resistor and a filament lamp.
5.1.10	Derive and apply expressions for electrical power dissipation in resistors.		
5.1.11	Solve problems involving potential difference, current and resistance.		

5.2 Electric circuits

	Assessment statement	Teacher's notes
5.2.1	Define *electromotive force* (*emf*).	
5.2.2	Describe the concept of internal resistance.	
5.2.3	Apply the equations for resistors in series and in parallel.	This includes combinations of resistors and also complete circuits involving internal resistance.
5.2.4	Draw circuit diagrams.	Students should be able to recognize and use the accepted circuit symbols.
5.2.5	Describe the use of ideal ammeters and ideal voltmeters.	Ammeters are connecting in series (in-line) to measure current and ideally have no resistance. Voltmeters are connected in parallel (across) a component and ideally have an infinite resistance
5.2.6	Describe a potential divider. A potential divider can be used to divide a potential difference to obtain the potential difference required by selecting values for R1 and R2.	
5.2.7	Explain the use of sensors in potential divider circuits. *Quarter-bridge strain gauge circuit* 	Sensors should include light-dependent resistors (LDRs), negative temperature coefficient (NTC) thermistors and strain gauges. **Light dependent resistor (LDR) and thermistor** This is a type of resistor which has a resistance that changes with the amount of LIGHT that falls on it. The light energy produces more free electrons which increases the current for a certain voltage across the LDR which means a drop in resistance. In the DARK its resistance is LARGE (millions of ohms), in the LIGHT its resistance is SMALL (tens of ohms). Very little current will flow through it in the dark. LDRs are used as light sensors.

		 THERMISTOR This is a type of resistor which has a resistance that changes with TEMPERATURE. The increasing temperature produces more free electrons and so the resistance falls. At LOW TEMPERATURE its resistance is LARGE (thousands of ohms), at HIGH TEMPERATURE its resistance is SMALL (tens of ohms). Very little current will flow through it when it is cold. This means that its resistance increases as the temperature falls. Thermistors are used as temperature sensors
5.2.8	Solve problems involving electric circuits.	Students should appreciate that many circuit problems may be solved by regarding the circuit as a potential divider. Students should be aware that ammeters and voltmeters have their own resistance.

Topic 6: Fields and forces

In this topic, the similarities and differences between the fields should be brought to the attention of students.

6.1 Gravitational force and field

	Assessment statement	Teacher's notes
6.1.1	State Newton's universal law of gravitation.	The masses in the force law are point masses. The force between two spherical masses whose separation is large compared to their radii is the same as if the two spheres were point masses with their masses concentrated at the centres of the spheres.
6.1.2	Define gravitational field strength.	Force exerted on a test point mass of 1kg.
6.1.3	Determine the gravitational field due to one or more point masses	Use of derived equation below: $g=GM_1/r^2$
6.1.4	Derive an expression for gravitational field strength at the surface of a planet, assuming that all its mass is concentrated at its centre	$g = F/M_2$ $F=GM_1M_2/r^2$ so $g = GM_1$~~M_2~~$/r^2$~~M_2~~ $g=GM_1/r^2$
6.1.5	Solve problems involving gravitational forces and fields.	

6.1 Electrical force and field

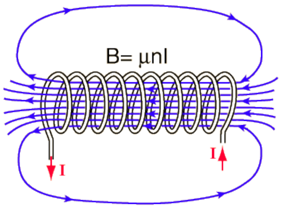
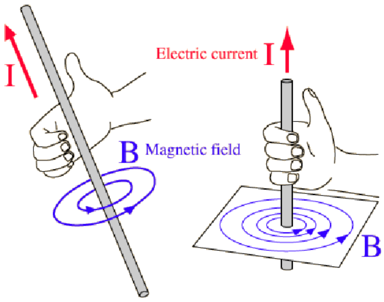
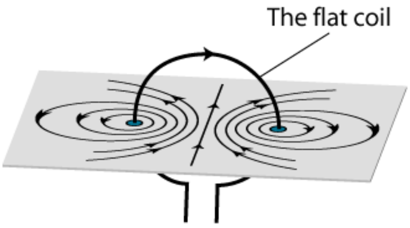
	Assessment statement	Teacher's notes
6.2.1	State that there are two types of electric charge.	Positive and negative See also discovery of the electron
6.2.2	State and apply the law of conservation of charge.	Charge cannot be created unequally so the total charge in a closed system cannot change. (Charge can be transferred).

6.2.3	Describe and explain the difference in the electrical properties of conductors and insulators.	Conductors have charged particles that are able to move through them.
6.2.4	State Coulomb's law. The force between charges varies as the inverse square of the distance	The scalar form of Coulomb's law is an expression for the magnitude and sign of the electrostatic force between two idealized point charges, small in size compared to their separation. This force (F) acting simultaneously on point charges (q_1) and (q_2), is given by $F = k_e \frac{q_1 q_2}{r^2}$ where r is the separation distance and k_e is a proportionality constant. A positive force implies it is repulsive, while a negative force implies it is attractive.[7] The proportionality constant k_e, called the Coulomb constant (sometimes called the Coulomb force constant), is related to defined properties of space and can be calculated based on the speed of light to be exactly:[8] $k_e = \frac{1}{4\pi\varepsilon_0} = \frac{c^2\mu_0}{4\pi} = c^2 \cdot 10^{-7}\ \mathrm{H \cdot m^{-1}}$ $= 8.987\ 551\ 787\ 368\ 176\ 4 \times 10^9\ \mathrm{N \cdot m^2/C^2}$
6.2.5	Define electric field strength.	Presentation on Electric Fields
6.2.6	Determine the electric field strength due to one or more point charges.	
6.2.7	Draw the electric field patterns for different charge configurations http://everythingscience.co.za/grade-11/17-electrostatics/17-electrostatics-03.cnxmlplus	These include the fields due to point charge (radial field), charged sphere, two point charges, oppositely charged plates including edge effect. Students should understand what is meant by radial field.
6.2.8	Solve problems involving electric charges, forces and fields.	

6.3 Magnetic force and field

2 hours

	Assessment statement	Teacher's notes
6.3.1	State that moving charges give rise to magnetic fields.	

6.3.2	Draw magnetic field patterns due to currents.  The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weak and divergent. To determine the magnetic field direction inside a solenoid you also used the right hand screw rule. The thumb becomes the field and your fingers the current	These include the fields due to currents in a straight wire, a flat circular coil and a solenoid. The diagram shows the right hand grip rule to show magnetic field around a current carrying wire.   Magnetic field pattern generated by a flat coil .

6.3.3	Determine the direction of the force on a current-carrying conductor in a magnetic field.	Different rules may be used to determine the force direction. Knowledge of any particular rule is not required. "The force on a wire is a right angles to the direction of the magnetic field" – Michael Faraday
6.3.4	Determine the direction of the force on a charge moving in a magnetic field.	Flemings left hand rule – note that the second finger represents positive current so is in the opposite direction to electron flow
6.3.5	Define the *magnitude* and *direction* of a magnetic field.	
6.3.6	Solve problems involving magnetic forces, fields and currents.	

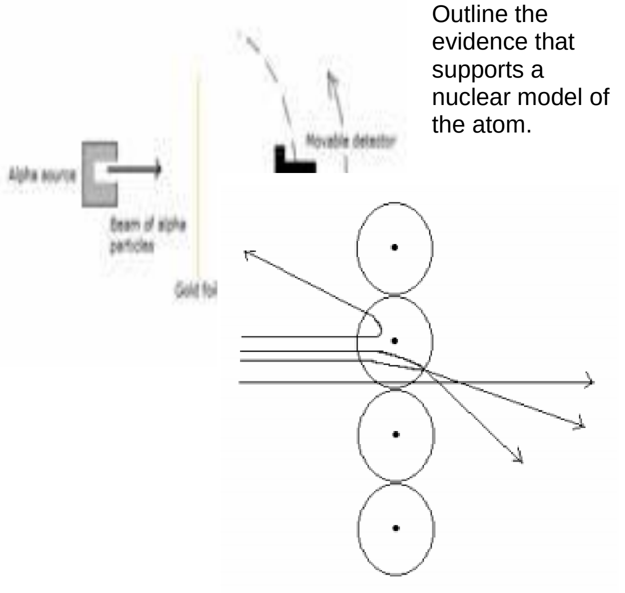
Topic 7: Atomic and nuclear physics (9 hours)

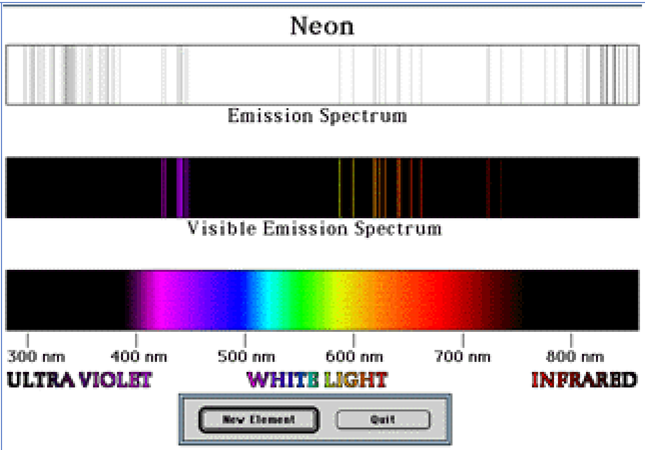
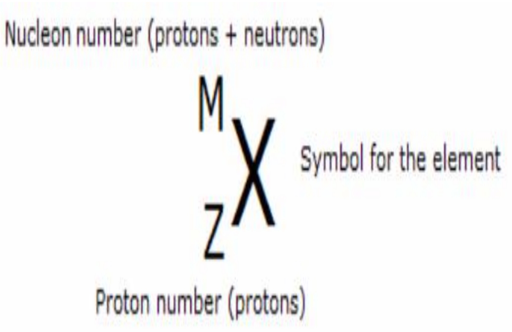
Aim 7: There are opportunities throughout this topic to look at databases, use spreadsheets, explore simulations and perform data-logging experiments.

http://timeline.aps.org/APS/Timeline/

7.1 The atom

2 hours

	Assessment statement	Obj	Teacher's notes
Atomic structure			
7.1.1	Describe a model of the atom that features a small nucleus surrounded by electrons.	2	Students should be able to describe a simple model involving electrons kept in orbit around the nucleus as a result of the electrostatic attraction between the electrons and the nucleus.
7.1.2	 Outline the evidence that supports a nuclear model of the atom.	2	A qualitative description of the Geiger–Marsden experiment and an interpretation of the results are all that is required… The best evidence for the nuclear model of the atom is the Geiger-Marsden Gold leaf experiment. They fired a beam of charged particles at a single layer of gold molecules and observed what happened. According to the JJ Thomson "Plum Pudding" model they were expecting the charged particles to pass straight through. They were very surprised that some of the alpha particles where deflected as they passed through the gold. From this they deduced that there the atom was made up of a small massive positively charged nucleus surrounded by space.
7.1.3	Outline one limitation of the simple model of the nuclear atom.	2	The problem with this theory was that accelerating charges are known to lose energy. If the orbiting electrons were to lose energy they would spiral into the nucleus. The Rutherford model cannot explain to us how atoms are stable.
7.1.4	Outline evidence for the existence of atomic energy levels.	2	Students should be familiar with emission and

			absorption spectra, but the details of atomic models are not required. Students should understand that light is not a continuous wave but is emitted as "packets" or "photons" of energy, each of energy *hf*.
Nuclear structure			
7.1.5	Explain the terms nuclide, isotope and nucleon.	3	Nuclide – protons and neutrons that form a nucleus Isotope – nuclei that have the same number of protons but a different number of neutrons. Nucleon – The collective name for particles that are found in the nucleus (protons and Neutrons)
7.1.6	Define *nucleon number A*, *proton number Z* and *neutron number N*. 	1	Nucleon Number, A – The number of protons and neutrons that are in the nucleus. Proton Number, Z – The number of protons that are in the nucleus. Neutron Number, N – The number of neutrons that are in the nucleus.
7.1.7	Describe the interactions in a nucleus.	2	Students need only know about the Coulomb interaction between protons and the strong, short-range nuclear interaction between nucleons.

7.2 Radioactive decay

3 hours

	Assessment statement	Obj	Teacher's notes
Radioactivity			
7.2.1	Describe the phenomenon of natural radioactive decay.	2	The inclusion of the antineutrino in β^- decay is required.
7.2.2	Describe the properties of alpha (α) and beta (β) particles and gamma (γ) radiation.	2	
7.2.3	Describe the ionizing properties of alpha (α) and beta (β) particles and gamma (γ) radiation.	2	
7.2.4	Outline the biological effects of ionizing radiation. https://www.jlab.org/div_dept/train/rad_guide/effects.html	2	Students should be familiar with the direct and indirect effects of radiation on structures within cells. A simple account of short-term and long-term effects of radiation on the body is required. **Aim 8:** There are moral, social and environmental aspects to consider here. **TOK:** Correlation and cause, and risk assessment, can also be looked at.

7.2.5	Explain why some nuclei are stable while others are unstable.	3	An explanation in terms of relative numbers of protons and neutrons and the forces involved is all that is required.
Half-life			
7.2.6	State that radioactive decay is a random and spontaneous process and that the rate of decay decreases exponentially with time.	1	Exponential decay need not be treated analytically. It is sufficient to know that any quantity that reduces to half its initial value in a constant time decays exponentially. The nature of the decay is independent of the initial amount.
7.2.7	Define the term *radioactive half-life*.	1	The time required for half the nuclei in a sample of a specific isotopic species to undergo radioactive decay
7.2.8	Determine the half-life of a nuclide from a decay curve.	3	http://www.darvill.clara.net/nucrad/hlife.htm
7.2.9	Solve radioactive decay problems involving integral numbers of half-lives.	3	http://www.esrl.noaa.gov/gmd/outreach/isotopes/decay.html http://www.answers.com/topic/radiocarbon-dating

7.3 Nuclear reactions, fission and fusion

4 hours

	Assessment statement	Obj	Teacher's notes
Nuclear reactions			
7.3.1	Describe and give an example of an artificial (induced) transmutation.	2	
7.3.2	Construct and complete nuclear equations.	3	
7.3.3	Define the term *unified atomic mass unit*.	1	Students must be familiar with the units MeV c^{-2} and GeV c^{-2} for mass.
7.3.4	Apply the Einstein mass–energy equivalence relationship.	2	
7.3.5	Define the concepts of *mass defect*, *binding energy* and *binding energy per nucleon*.	1	
7.3.6	Draw and annotate a graph showing the variation with nucleon number of the binding energy per nucleon.	2	Students should be familiar with binding energies plotted as positive quantities.
7.3.7	Solve problems involving mass defect and binding energy.	3	
Fission and fusion			
7.3.8	Describe the processes of nuclear fission and nuclear fusion.	2	
7.3.9	Apply the graph in 7.3.6 to account for the energy release in the processes of fission and fusion.	2	The binding energy difference per nucleon between Uramium and its daughter nuclei is smaller than the difference between hydrogen (or its isotopes) and helium. Hydrogen isotopes fusing to Helium therefore release more energy per gram than fission of Uranium.
7.3.10	State that nuclear fusion is the main source of the Sun's energy.	1	
7.3.11	Solve problems involving fission and fusion reactions.	3	

Topic 8: Energy, power and climate change (18 hours)

Aim 8 and the international dimension feature strongly in all the sub-topics.

8.1 Energy degradation and power generation

2 hours

Aim 7: Computer simulations of Sankey diagrams feature here.

	Assessment statement	Obj	Teacher's notes
8.1.1	State that thermal energy may be completely converted to work in a single process, but that continuous conversion of this energy into work requires a cyclical process and the transfer of some energy from the system.	1	
8.1.2	Explain what is meant by degraded energy.	3	Students should understand that, in any process that involves energy transformations, the energy that is transferred to the surroundings (thermal energy) is no longer available to perform useful work.
8.1.3	Construct and analyse energy flow diagrams (Sankey diagrams) and identify where the energy is degraded.	3	It is expected that students will be able to construct flow diagrams for various systems including those described in sub-topics 8.3 and 8.4.
8.1.4	Outline the principal mechanisms involved in the production of electrical power.	2	Students should know that electrical energy may be produced by rotating coils in a magnetic field. In sub-topics 8.2 and 8.3 students look in more detail at energy sources used to provide the energy to rotate the coils.

8.2World energy sources

2 hours

Aim 7: Databases of energy statistics on a global and national scale can be explored here. Moral, environmental and economic aspects may be considered.

	Assessment statement	Obj	Teacher's notes
8.2.1	Identify different world energy sources.	2	Students should be able to recognize those sources associated with CO_2 emission. Students should also appreciate that, in most instances, the Sun is the prime energy source for world energy.
8.2.2	Outline and distinguish between renewable and non-renewable energy sources.	2	
8.2.3	Define the *energy density* of a fuel.	1	Energy density is measured in $J\ kg^{-1}$.
8.2.4	Discuss how choice of fuel is influenced by its energy density.	3	The values of energy density of different fuels will be provided.
8.2.5	State the relative proportions of world use of the different energy sources that are available.	1	Only approximate values are needed.
8.2.6	Discuss the relative advantages and disadvantages of various energy sources.	3	The discussion applies to all the sources identified in sub-topics 8.2, 8.3 and 8.4.

8.3 Fossil fuel power production

1 hour

	Assessment statement	Obj	Teacher's notes
8.3.1	Outline the historical and geographical reasons for the widespread use of fossil fuels.	2	Students should appreciate that industrialization led to a higher rate of energy usage, leading to industry being developed near to large deposits of fossil fuels.
8.3.2	Discuss the energy density of fossil fuels with respect to the demands of power stations.	3	Students should be able to estimate the rate of fuel consumption by power stations.
8.3.3	Discuss the relative advantages and disadvantages associated with the transportation and storage of fossil fuels.	3	

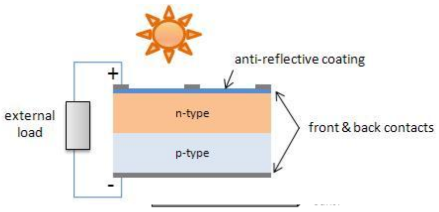
8.3.4	State the overall efficiency of power stations fuelled by different fossil fuels.	1	Only approximate values are required. natural gas power stations 50%, oil fired power stations 40%, coal fired powered stations 40%, combined heat and power plants 90%
8.3.5	Describe the environmental problems associated with the recovery of fossil fuels and their use in power stations.	2	

8.4 Non-fossil fuel power production

7 hours

Aim 7: Computer simulations may be shown modelling nuclear power stations and nuclear processes in general.

	Assessment statement	Obj	Teacher's notes
Nuclear power			
8.4.1	Describe how neutrons produced in a fission reaction may be used to initiate further fission reactions (chain reaction).	2	Students should know that only low-energy neutrons (≈ 1 eV) favour nuclear fission. They should also know about critical mass.
8.4.2	Distinguish between controlled nuclear fission (power production) and uncontrolled nuclear fission (nuclear weapons).	2	Students should be aware of the moral and ethical issues associated with nuclear weapons.
8.4.3	Describe what is meant by fuel enrichment.	2	Increasing the percentage of U-235 so that critical mass of U-235 can be achieved and fission chain reaction is viable.
8.4.4	Describe the main energy transformations that take place in a nuclear power station.	2	
8.4.5	Discuss the role of the moderator and the control rods in the production of controlled fission in a thermal fission reactor.	3	
8.4.6	Discuss the role of the heat exchanger in a fission reactor.	3	
8.4.7	Describe how neutron capture by a nucleus of uranium-238 (^{238}U) results in the production of a nucleus of plutonium-239 (^{239}Pu).	2	
8.4.8	Describe the importance of plutonium-239 (^{239}Pu) as a nuclear fuel.	2	It is sufficient for students to know that plutonium-239 (^{239}Pu) is used as a fuel in other types of reactors.
8.4.9	Discuss safety issues and risks associated with the production of nuclear power.	3	Such issues involve: • the possibility of thermal meltdown and how it might arise • problems associated with nuclear waste • problems associated with the mining of uranium • the possibility that a nuclear power programme may be used as a means to produce nuclear weapons.
8.4.10	Outline the problems associated with producing nuclear power using nuclear fusion.	2	It is sufficient that students appreciate the problem of maintaining and confining a high-temperature, high-density plasma. Because the pressures on Earth are no where near the pressures in the Sun deuterium-tritium fusion (the lowest temperature fission) needs temperatures of order of magnitude 10^7. This means that the plasma cannot be touching anything. It is held in a Taurus ring by powerful superconduting electromagnets. Energy is supplied by……
8.4.11	Solve problems on the production of nuclear power.	3	
Solar power			

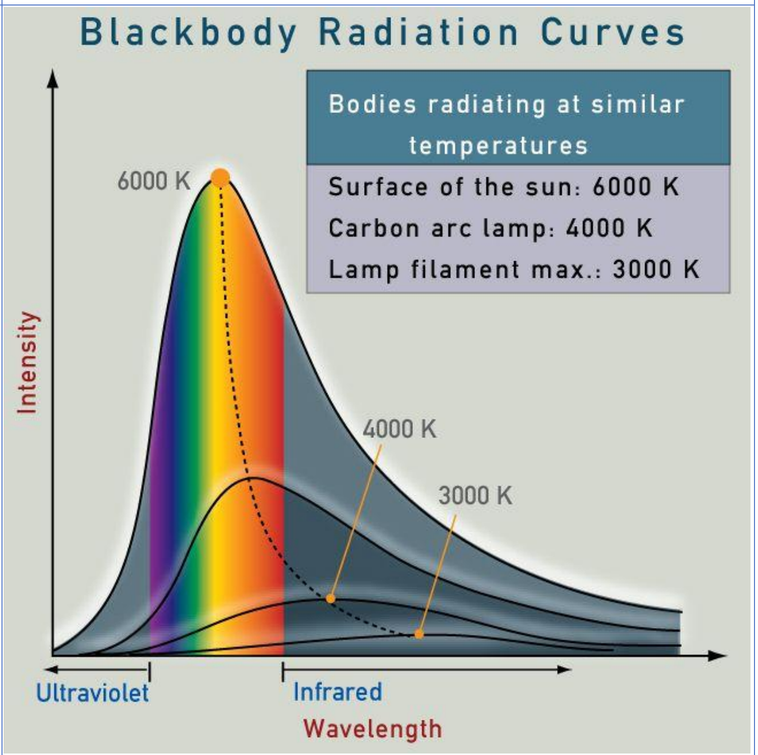
8.4.12	Distinguish between a photovoltaic cell and a solar heating panel. 	2	Students should be able to describe the energy transfers involved and outline appropriate uses of these devices. The knowledge you need for the exam is that the PV cell uses the photo-electric effect to create a DC electrical supply and the solar heating panel uses sunlight falling on dark pipes with water that heats up due to the sun's rays being absorbed. The solar heating panel is covered to prevent heat loss from convection. PV: Light ➔ Electricity Heating panel: Light ➔ Thermal
8.4.13	Outline reasons for seasonal and regional variations in the solar power incident per unit area of the Earth's surface.	2	
8.4.14	Solve problems involving specific applications of photovoltaic cells and solar heating panels.	3	
Hydroelectric power			
8.4.15	Distinguish between different hydroelectric schemes.	2	Students should know that the different schemes are based on: • water storage in lakes • tidal water storage • pump storage.
8.4.16	Describe the main energy transformations that take place in hydroelectric schemes.	2	
8.4.17	Solve problems involving hydroelectric schemes.	3	
Wind power			
8.4.18	Outline the basic features of a wind generator.	2	A conventional horizontal-axis machine is sufficient.
8.4.19	Determine the power that may be delivered by a wind generator, assuming that the wind kinetic energy is completely converted into mechanical kinetic energy, and explain why this is impossible.	3	
8.4.20	Solve problems involving wind power.	3	
Wave power			
8.4.21	Describe the principle of operation of an oscillating water column (OWC) ocean-wave energy converter.	2	Students should be aware that energy from a water wave can be extracted in a variety of different ways, but only a description of the OWC is required.
8.4.22	Determine the power per unit length of a wavefront, assuming a rectangular profile for the wave.	3	
8.4.23	Solve problems involving wave power.	3	

8.5 Greenhouse effect

3 hours

Aim 7: Computer simulation, spreadsheets and databases have a significant role here.

Solar radiation			
8.5.1	Calculate the intensity of the Sun's radiation incident on a planet.	2	
8.5.2	Define *albedo*.	1	

8.5.3	State factors that determine a planet's albedo.	1	Students should know that the Earth's albedo varies daily and is dependent on season (cloud formations) and latitude. Oceans have a low value but snow a high value. The global annual mean albedo is 0.3 (30%) on Earth.
The greenhouse effect			
8.5.4	Describe the greenhouse effect.	2	
8.5.5	Identify the main greenhouse gases and their sources.	2	The gases to be considered are CH_4, H_2O, CO_2 and N_2O. It is sufficient for students to know that each has natural and man-made origins.
8.5.6	Explain the molecular mechanisms by which greenhouse gases absorb infrared radiation.	3	Students should be aware of the role played by resonance. The natural frequency of oscillation of the molecules of greenhouse gases is in the infrared region.
8.5.7	Analyse absorption graphs to compare the relative effects of different greenhouse gases.	3	Students should be familiar with, but will not be expected to remember, specific details of graphs showing infrared transmittance through a gas.
8.5.8	Outline the nature of black-body radiation.	2	Students should know that black-body radiation is the radiation emitted by a "perfect" emitter.
8.5.9	Draw and annotate a graph of the emission spectra of black bodies at different temperatures.	2	
8.5.10	State the Stefan–Boltzmann law and apply it to compare emission rates from different surfaces.	2	
8.5.11	Apply the concept of emissivity to compare the emission rates from the different surfaces.	2	
8.5.12	Define *surface heat capacity* C_s.	1	Surface heat capacity is the energy required to raise the temperature of unit area of a planet's surface by one degree, and is measured in J m^{-2} K^{-1}.
8.5.13	Solve problems on the greenhouse effect and the heating of planets using a simple energy balance climate model.	3	Students should appreciate that the change of a planet's temperature over a period of time is given by: (incoming radiation intensity – outgoing radiation intensity) × time / surface heat capacity. Students should be aware of limitations of the model and suggest how it may be improved. **Aim 7:** A spreadsheet should be used to show a simple climate model.

			Computer simulations could be used to show more complex models (see OCC for details). **TOK:** The use and importance of computer modelling can be explained as a powerful means by which knowledge may be gained.

8.6 Global warming

3 hours

Int: The importance of the international dimension in scientific research to solve global problems can be demonstrated here.

	Assessment statement	Obj	Teacher's notes
Global warming			
8.6.1	Describe some possible models of global warming.	2	Students must be aware that a range of models has been suggested to explain global warming, including changes in the composition of greenhouse gases in the atmosphere, increased solar flare activity, cyclical changes in the Earth's orbit and volcanic activity.
8.6.2	State what is meant by the enhanced greenhouse effect.	1	It is sufficient for students to be aware that enhancement of the greenhouse effect is caused by human activities.
8.6.3	Identify the increased combustion of fossil fuels as the likely major cause of the enhanced greenhouse effect.	2	Students should be aware that, although debatable, the generally accepted view of most scientists is that human activities, mainly related to burning of fossil fuels, have released extra carbon dioxide into the atmosphere.
8.6.4	Describe the evidence that links global warming to increased levels of greenhouse gases.	2	For example, international ice core research produces evidence of atmospheric composition and mean global temperatures over thousands of years (ice cores up to 420,000 years have been drilled in the Russian Antarctic base, Vostok).
8.6.5	Outline some of the mechanisms that may increase the rate of global warming.	2	Students should know that: • global warming reduces ice/snow cover, which in turn changes the albedo, to increase rate of heat absorption • temperature increase reduces the solubility of CO_2 in the sea and increases atmospheric concentrations • deforestation reduces carbon fixation.
8.6.6	Define *coefficient of volume expansion*.	1	Students should know that the coefficient of volume expansion is the fractional change in volume per degree change in temperature.
8.6.7	State that one possible effect of the enhanced greenhouse effect is a rise in mean sea-level.	1	
8.6.8	Outline possible reasons for a predicted rise in mean sea-level.	2	Students should be aware that precise predictions are difficult to make due to factors such as: • anomalous expansion of water • different effects of ice melting on sea water compared to ice melting on land.
8.6.9	Identify climate change as an outcome of the enhanced greenhouse effect.	2	
8.6.10	Solve problems related to the enhanced greenhouse effect.	3	Problems could involve volume expansion, specific heat capacity and latent heat.
8.6.11	Identify some possible solutions to reduce the enhanced greenhouse effect.	2	Students should be aware of the following: • greater efficiency of power production • replacing the use of coal and oil with natural gas • use of combined heating and power systems (CHP) • increased use of renewable energy sources and nuclear power • carbon dioxide capture and storage • use of hybrid vehicles.

8.6.12	Discuss international efforts to reduce the enhanced greenhouse effect.	3	These should include, for example: • Intergovernmental Panel on Climate Change (IPCC) • Kyoto Protocol • Asia-Pacific Partnership on Clean Development and Climate (APPCDC).

Topic 9: Motion in fields (8 hours)

As in topic 6, the similarities and differences between the fields also apply to potential.

Aim 7: This topic lends itself to the use of modelling with spreadsheets and simulations to illustrate the concepts addressed.

http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/ProjectileMotion/jarapplet.html

TOK: This topic includes how fundamental concepts may be applied to different phenomena.

9.1 Projectile motion

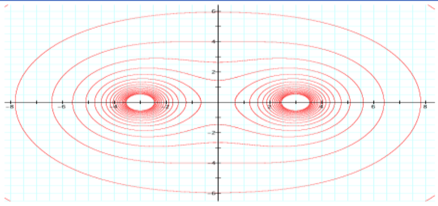
2 hours

	Assessment statement	Obj	Teacher's notes
9.1.1	State the independence of the vertical and the horizontal components of velocity for a projectile in a uniform field.	1	
9.1.2	Describe and sketch the trajectory of projectile motion as parabolic in the absence of air resistance.	3	Proof of the parabolic nature of the trajectory is not required.
9.1.3	Describe qualitatively the effect of air resistance on the trajectory of a projectile.	2	
9.1.4	Solve problems on projectile motion.	3	Problems may involve projectiles launched horizontally or at any angle above or below the horizontal. Applying conservation of energy may provide a simpler solution to some problems than using projectile motion kinematics equations.

9.2 Gravitational field, potential and energy

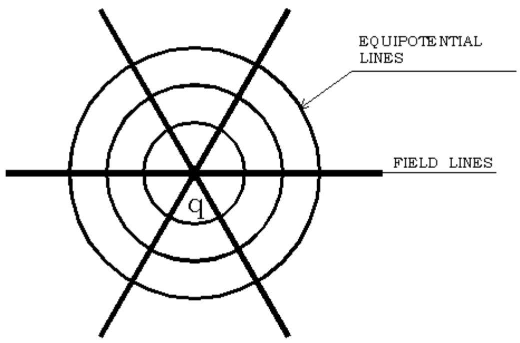
2 hours

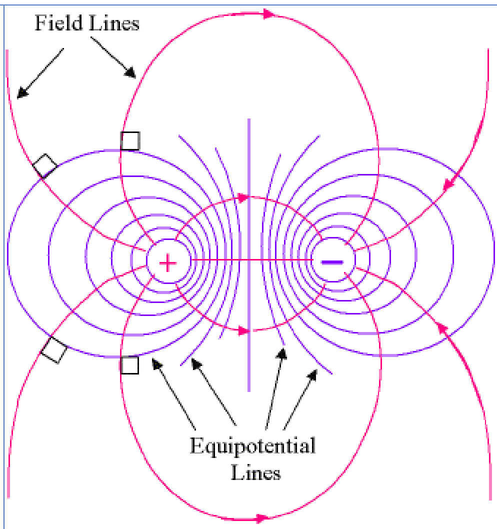
	Assessment statement	Obj	Teacher's notes
9.2.1	Define gravitational potential and gravitational potential energy.	1	Students should understand the scalar nature of gravitational potential and that the potential atinfinity is taken as zero. Students should understand that the work done in moving a mass between two points in a gravitational field is independent of the path taken
9.2.2	State and apply the expression for gravitational potential due to a point mass.	2	
9.2.3	State and apply the formula relating gravitational field strength to gravitational potential gradient.	2	
9.2.4	Determine the potential due to one or more point masses.	3	

9.2.5	Describe and sketch the pattern of equipotential surfaces due to one and two point masses. Two point mass shown here ➔	3	
9.2.6	State the relation between equipotential surfaces and gravitational field lines.	1	
9.2.7	Explain the concept of escape speed from a planet.	3	Total energy is zero at escape velocity because the kinetic energy is just enough to place the object infinitely far away from the planet
9.2.8	Derive an expression for the escape speed of an object from the surface of a planet.	3	Students should appreciate the simplifying assumptions in this derivation: Planetary spin is ignored and resistance due to atmosphere is ignored. It is also assume planets is spherical with fairly vonstant density.
9.2.9	Solve problems involving gravitational potential energy and gravitational potential.	3	http://www.neutrinophysics.com/gravitational-field-potential-and-energy.html

9.2 Electric field, potential and energy

2 hours

	Assessment statement	Obj	Teacher's notes
9.3.1	Define electric potential and electric potential energy.	1	Students should understand the scalar nature of electric potential and that the potential at infinity is taken as zero. Students should understand that the work done in moving a point charge between two points in an electric field is independent of the path taken.
9.3.2	State and apply the expression for electric potential due to a point charge.	2	
9.3.3	State and apply the formula relating electric field strength to electric potential gradient.	2	
9.3.4	Determine the potential due to one or more point charges.	3	
9.3.5	Describe and sketch the pattern of equipotential surfaces due to one and two point charges.	3	

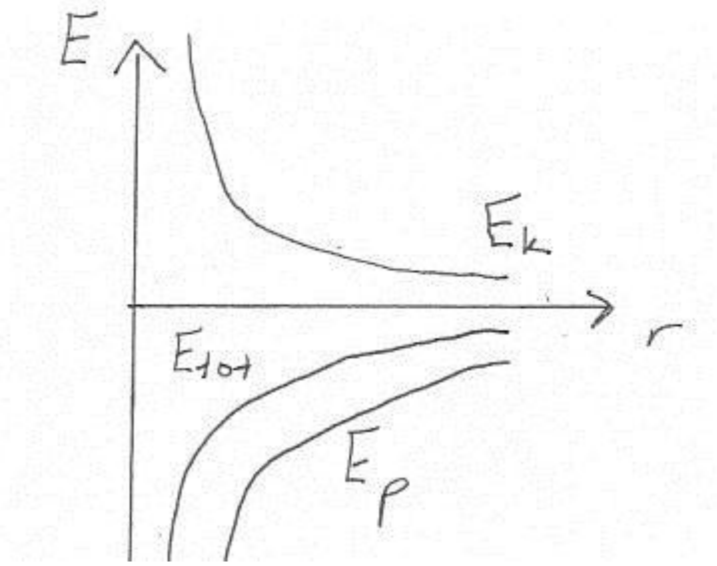
9.3.6	State the relation between equipotential surfaces and electric field lines. The are perpendicular to each other.	1	
9.3.7	Solve problems involving electric potential energy and electric potential	3	

9.4 Orbital motion

2 hours

Although orbital motion may be circular, elliptical or parabolic, this sub-topic only deals with circular orbits. This sub-topic is not fundamentally new physics, but an application that synthesizes ideas from gravitation, circular motion, dynamics and energy.

	Assessment statement	Obj	Teacher's notes
9.4.1	State that gravitation provides the centripetal force for circular orbital motion.	1	
9.4.2	Derive Kepler's third law.	3	The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)
9.4.3	Derive expressions for the kinetic energy, potential energy and total energy of an orbiting satellite (stable orbit)	3	Potential energy from GM/R, KE from centripetal accel = g, total is sum of these. Fianl answers should be: • $E_k = ½mv^2$ **$= Gm_1m_2/2r$** • E_p **$= -Gm_1m_2/r$** • $E_t = E_k + E_p$ = **$- Gm_1m_2/2r$**

9.4.4	Sketch graphs showing the variation with orbital radius of the kinetic energy, gravitational potential energy and total energy of a satellite.	3	
9.4.5	Discuss the concept of “weightlessness” in orbital motion, in free fall and in deep space.	3	
9.4.6	Solve problems involving orbital motion.	3	

Topic 10: Thermal physics (6 hours)

10.1 Thermodynamics

2 hours

	Assessment statement	Obj	Teacher’s notes
Gas laws			
10.1.1	State the equation of state for an ideal gas.	1	Students should be aware that an ideal gas is one that has the equation of state $PV = nRT$ and that this equation also defines the universal gas constant R.
10.1.2	Describe the difference between an ideal gas and a real gas.	2	Students should be aware of the circumstances in which real gas behaviour approximates to ideal gas behaviour. Students should also appreciate that ideal gases cannot be liquefied.
10.1.3	Describe the concept of the absolute zero of temperature and the Kelvin scale of temperature.	2	
10.1.4	Solve problems using the equation of state of an ideal gas.	3	

10.2 Processes

3 hours

Although there are many thermodynamic systems, in this sub-topic discussion will be restricted to a fixed mass of an ideal gas.

	Assessment statement	Obj	Teacher’s notes
The first law of thermodynamics			
10.2.1	Deduce an expression for the work involved in a	3	

	volume change of a gas at constant pressure.		
10.2.2	State the first law of thermodynamics.	1	Students should be familiar with the terms system and surroundings. They should also appreciate that if a system and its surroundings are at different temperatures and the system undergoes a process, the energy transferred by non-mechanical means to or from the system is referred to as thermal energy (heat).
10.2.3	Identify the first law of thermodynamics as a statement of the principle of energy conservation.	2	
10.2.4	Describe the isochoric (isovolumetric), isobaric, isothermal and adiabatic changes of state of an ideal gas.	2	In each process, the energy transferred, the work done and the internal energy change should be addressed. Students should realize that a rapid compression or expansion of a gas is approximately adiabatic.
10.2.5	Draw and annotate thermodynamic processes and cycles on *P*–*V* diagrams.	2	
10.2.6	Calculate from a *P*–*V* diagram the work done in a thermodynamic cycle.	2	
10.2.7	Solve problems involving state changes of a gas.	3	

10.3 Second law of thermodynamics and entropy

1 hour

	Assessment statement	Obj	Teacher's notes
10.3.1	State that the second law of thermodynamics implies that thermal energy cannot spontaneously transfer from a region of low temperature to a region of high temperature.	1	
10.3.2	State that entropy is a system property that expresses the degree of disorder in the system.	1	
10.3.3	State the second law of thermodynamics in terms of entropy changes.	1	A statement that the overall entropy of the universe is increasing will suffice or that all natural processes increase the entropy of the universe.
10.3.4	Discuss examples of natural processes in terms of entropy changes.	3	Students should understand that, although local entropy may decrease, any process will increase the total entropy of the system and surroundings, that is, the universe. Change of entropy = Change inTemperature divided by temperature.

Topic 11: Wave phenomena (12 hours)

Aim 7: Computer simulations could be very helpful in illustrating concepts introduced in this topic.

11.1 Standing (stationary) waves

2 hours

	Assessment statement	Obj	Teacher's notes
11.1.1	Describe the nature of standing (stationary) waves.	2	Students should consider energy transfer, amplitude and phase.
11.1.2	Explain the formation of one-dimensional standing waves.	3	Students should understand what is meant by nodes and antinodes.
11.1.3	Discuss the modes of vibration of strings and air in open and in closed pipes.	3	The lowest-frequency mode is known either as the fundamental or as the first harmonic. The term overtone will not be used.
11.1.4	Compare standing waves and travelling waves.	3	
11.1.5	Solve problems involving standing waves.	3	

11.2 Doppler effect

2 hours

	Assessment statement	Obj	Teacher's notes
11.2.1	Describe what is meant by the Doppler effect.	2	
11.2.2	Explain the Doppler effect by reference to wavefront diagrams for moving-detector and moving-source situations.	3	
11.2.3	Apply the Doppler effect equations for sound.	2	
11.2.4	Solve problems on the Doppler effect for sound.	3	Problems will not include situations where both source and detector are moving.
11.2.5	Solve problems on the Doppler effect for electromagnetic waves using the approximation .	3	Students should appreciate that the approximation may be used only when .
11.2.6	Outline an example in which the Doppler effect is used to measure speed.	2	Suitable examples include blood-flow measurements and the measurement of vehicle speeds.

11.3 Diffraction

1 hour

	Assessment statement	Obj	Teacher's notes
Diffraction at a single slit			
11.3.1	Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit.	3	
11.3.2	Derive the formula $\theta = \lambda / b$ for the position of the first minimum of the diffraction pattern produced at a single slit.	3	
11.3.3	Solve problems involving single-slit diffraction.	3	

11.4 Resolution

4 hours

	Assessment statement	Obj	Teacher's notes
11.4.1	Sketch the variation with angle of diffraction of the relative intensity of light emitted by two point sources that has been diffracted at a single slit.	3	Students should sketch the variation where the diffraction patterns are well resolved, just resolved and not resolved.
11.4.2	State the Rayleigh criterion for images of two sources to be just resolved.	1	Students should know that the criterion for a circular aperture is .
11.4.3	Describe the significance of resolution in the development of devices such as CDs and DVDs, the electron microscope and radio telescopes.	2	
11.4.4	Solve problems involving resolution.	3	Problems could involve the human eye and optical instruments.

11.5 Polarization

3 hours

	Assessment statement	Obj	Teacher's notes
11.5.1	Describe what is meant by polarized light.	2	

11.5.2	Describe polarization by reflection.	2	This may be illustrated using light or microwaves. The use of polarized sunglasses should be included.
11.5.3	State and apply Brewster's law.	2	
11.5.4	Explain the terms polarizer and analyser.	3	
11.5.5	Calculate the intensity of a transmitted beam of polarized light using Malus' law.	2	
11.5.6	Describe what is meant by an optically active substance.	2	Students should be aware that such substances rotate the plane of polarization.
11.5.7	Describe the use of polarization in the determination of the concentration of certain solutions.	2	
11.5.8	Outline qualitatively how polarization may be used in stress analysis.	2	
11.5.9	Outline qualitatively the action of liquid-crystal displays (LCDs).	2	**Aim 8:** The use of LCD screens in a wide variety of different applications/devices can be mentioned.
11.5.10	Solve problems involving the polarization of light.		

Topic 12: Electromagnetic induction (6 hours)

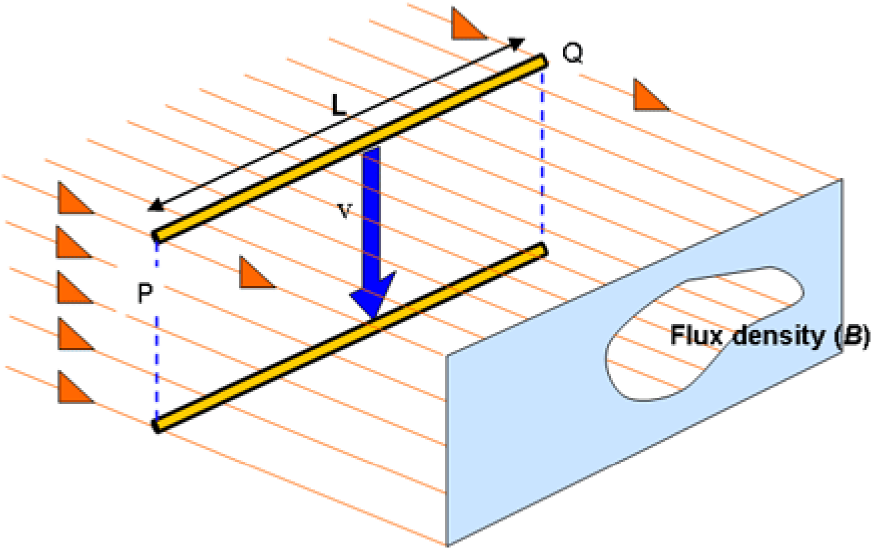
Generator simulation
http://www.walter-fendt.de/ph14e/generator_e.htm

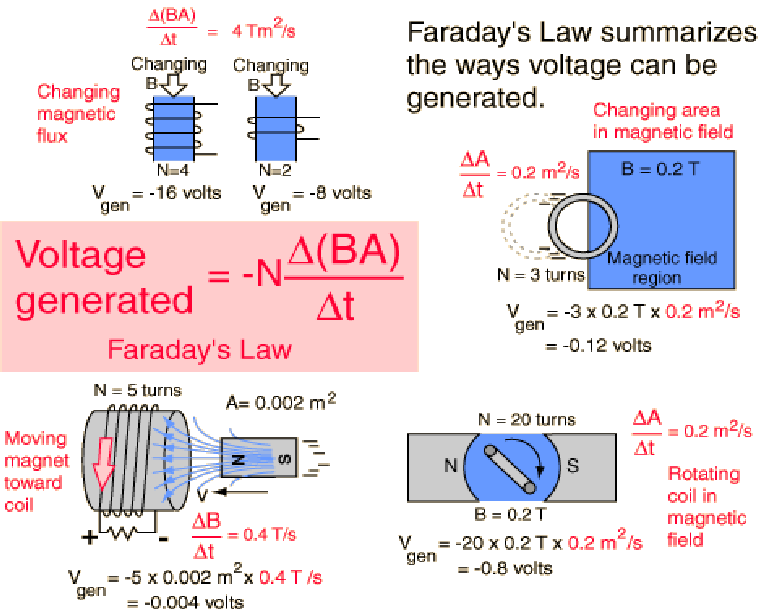
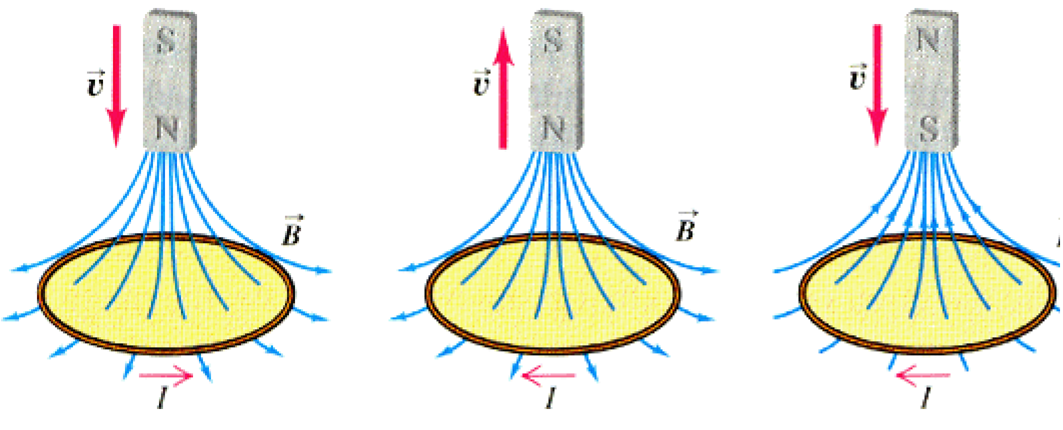
This topic leads to an understanding of generators and transformers

12.1 Induced electromotive force (emf)

3 hours

	Assessment statement	Teacher's notes
12.1.1	Describe the inducing of an emf by relative motion between a conductor and a magnetic field.	
12.1.2	Derive the formula for the emf induced in a straight conductor moving in a magnetic field.	Students should be able to derive the expression induced emf = Blv without using Faraday's law.

		 An electron in the bar of length L, experiences a force (=Bev) due to its motion in a magnetic field and moves. The displaced electrons set up an voltage difference V between the two ends of the bar. The electric field in the bar has a strength E = V/l. The Electric field exerts an electric force (=Ee) in the opposite direction to the displacement of the electrons. An equilibrium will be achieved and the forces will balance (Bev=Ee). Therefore Bv = V/L so Induced emf (V) = BLv. http://nothingnerdy.wikispaces.com/12.1+INDUCED+ELECTROMOTIVE+FORCE
12.1.3	Define *magnetic flux* and *magnetic flux linkage*.	*Magnetic flux:* The total amount of magnetism. This can be represented by the field lines. Symbol Φ, Unit Weber (Wb) *Magnetic flux* = Magnetic flux density x Area *Magnetic flux density:* A vector quantity measuring the strength and direction of the magnetic field around a magnet or an electric current. Symbol B, Units Tesla. Magnetic flux density also can be understood as the density of magnetic lines of force, or magnetic flux lines, passing through a specific area. Flux lines are also called magnetic flux, magnetic induction. Magnetic flux density is equal to magnetic field strength times the magnetic permeability in the region in which the field exists. Electric charges moving through a magnetic field are subject to a force described by the equation F = qv × B, where q is the amount of electric charge, v is the velocity of the charge, B is the magnetic flux density at the position of the charge, and × is the vector product. *Magnetic flux linkage*: the product of the magnetic flux and the number of turns in a given coil.

<table>
<tr><td>12.1.4</td><td>Describe the production of an induced emf by a time-changing magnetic flux.</td><td>
</td></tr>
<tr><td>12.1.5</td><td>State Faraday's law and Lenz's law.</td><td>Faraday's law: "The induced emf in a circuit is equal to the rate of change of flux through the circuit." This equals the rate at which flux linkage changes.


(a) (b) (c)
Lenz's law: "An induced current is always in such a direction as to oppose the motion or change causing it" (both from Wikipedia)</td></tr>
<tr><td>12.1.6</td><td>Solve electromagnetic induction problems.</td><td></td></tr>
</table>

12.2 Alternating current

Aim 7: Computer simulations of ac generators are a useful means to assess understanding: http://www.walter-fendt.de/ph14e/generator_e.htm

	Assessment statement	Obj	Teacher's notes
12.2.1	Describe the emf induced in a coil rotating within a uniform magnetic field.	2	The induced emf is caused by the motion of the wires in the armature cutting across the magnetic field. The rate at which they cut across this field is given by vcos(x) where v is the velocity of the wire and x is the angle the wire is travelling at (0 degrees meaning the wire is travelling perpendicular to the field)
12.2.2	Explain the operation of a basic alternating current (ac) generator.	3	
12.2.3	Describe the effect on the induced emf of changing the generator frequency.	2	Students will be expected to compare the output from generators operating at different frequencies by sketching appropriate graphs.
12.2.4	Discuss what is meant by the root mean squared (rms) value of an alternating current or voltage.	3	Students should know that the rms value of an alternating current (or voltage) is that value of the direct current (or voltage) that dissipates power in a resistor at the same rate. The rms value is also known as the rating.
12.2.5	State the relation between peak and rms values for sinusoidal currents and voltages.	1	
12.2.6	Solve problems using peak and rms values.	3	
12.2.7	Solve ac circuit problems for ohmic resistors.	3	
12.2.8	Describe the operation of an ideal transformer.	2	
12.2.9	Solve problems on the operation of ideal transformers.	3	

12.3 Transmission of electrical power

1 hour

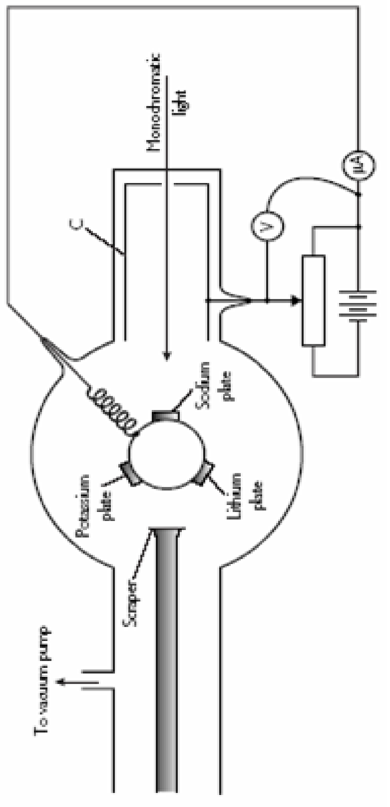
	Assessment statement	Obj	Teacher's notes
12.3.1	Outline the reasons for power losses in transmission lines and real transformers.	2	
12.3.2	Explain the use of high-voltage step-up and step-down transformers in the transmission of electrical power.	3	Students should be aware that, for economic reasons, there is no ideal value of voltage for electrical transmission.
12.3.3	Solve problems on the operation of real transformers and power transmission.	3	
12.3.4	Suggest how extra-low-frequency electromagnetic fields, such as those created by electrical appliances and power lines, induce currents within a human body.	3	
12.3.5	Discuss some of the possible risks involved in living and working near high-voltage power lines.	3	Students should be aware that current experimental evidence suggests that low-frequency fields do not harm genetic material. Students should appreciate that the risks attached to the inducing of current in the body are not fully understood. These risks are likely to be dependent on current (density), frequency and length of exposure. **Aim 8 and TOK:** The use of risk assessment in making scientific decisions can be discussed here. The issues of correlation and cause, and the limitations of data, are also relevant here.

Topic 13: Quantum physics and nuclear physics (15 hours)

http://dev.physicslab.org/Document.aspx?doctype=3&filename=AtomicNuclear_PhotoelectricEffect.xml

TOK: This topic raises fundamental philosophical problems related to the nature of observation and measurement. The concept of paradigm shift can be developed here.

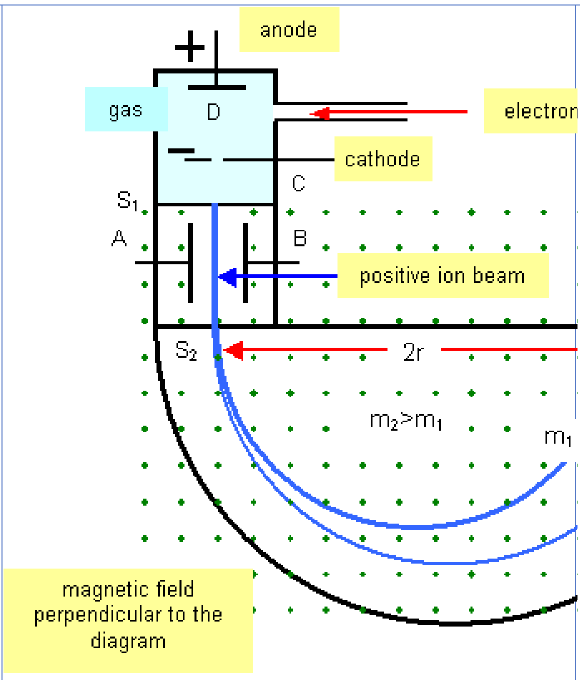
13.1 Quantum physics

	Assessment statement	Obj	Teacher's notes
The quantum nature of radiation			
13.1.1	Describe the photoelectric effect.	2	
13.1.2	Describe the concept of the photon, and use it to explain the photoelectric effect.	3	Students should be able to explain why the wave model of light is unable to account for the photoelectric effect, and be able to describe and explain the Einstein model.
13.1.3	Describe and explain an experiment to test the Einstein model.  	3	Millikan's experiment involving the application of a stopping potential would be suitable. **The Millikan experiment to verify Einstein's photo-electric relationship.** The photoelectric effect was – well known by the end of the 19th century. Its explanation was one of Einstein's first applications of his photon model for light. He devised an equation relating the energy of the photoelectrons to the frequency of the light and the work function of the metal used. In 1916, American physicist Robert Millikan completed some experiments that tested Einstein's equation. Though Millikan had been firmly against quantum theory, the results convinced him that Einstein was right. In Millikan's photoelectric apparatus, monochromatic light was incident on each of the newly-cleaned metal plates in turn. The resulting photoelectrons were collected by electrode C and flowed, via the variable resistor and microammeter, back to the plate assembly. By adjusting the potentiometer, Millikan found the potential difference that was just large enough to stop the electrons moving round the circuit. For each metal, he used radiation of several different frequencies, noting the `stopping voltage' for each. This graph shows some of his results for sodium.
13.1.4	Solve problems involving the photoelectric effect.	3	
The wave nature of matter			

13.1.5	Describe the de Broglie hypothesis and the concept of matter waves.	2	Students should also be aware of wave–particle duality (the dual nature of both radiation and matter).
13.1.6	Outline an experiment to verify the de Broglie hypothesis.	2	A brief outline of the Davisson–Germer experiment will suffice. Before understanding this you should look at X-ray diffraction.
13.1.7	Solve problems involving matter waves.	3	For example, students should be able to calculate the wavelength of electrons after acceleration through a given potential difference.
Atomic spectra and atomic energy states			
13.1.8	Outline a laboratory procedure for producing and observing atomic spectra.	2	Students should be able to outline procedures for both emission and absorption spectra. Details of the spectrometer are not required.
13.1.9	Explain how atomic spectra provide evidence for the quantization of energy in atoms.	3	An explanation in terms of energy differences between allowed electron energy states is sufficient.
13.1.10	Calculate wavelengths of spectral lines from energy level differences and vice versa.	2	**Aim 7:** Computer simulations showing the link between energy level transitions and spectral lines assist understanding.
13.1.11	Explain the origin of atomic energy levels in terms of the "electron in a box" model.	3	The model assumes that, if an electron is confined to move in one dimension by a box, the de Broglie waves associated with the electron will be standing waves of wavelength where *L* is the length of the box and *n* is a positive integer. Students should be able to show that the kinetic energy E_K of the electron in the box is .
13.1.12	Outline the Schrödinger model of the hydrogen atom.	2	The model assumes that electrons in the atom may be described by wavefunctions. The electron has an undefined position, but the square of the amplitude of the wavefunction gives the probability of finding the electron at a particular point.
13.1.13	Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy.	2	Students should be aware that the conjugate quantities, position–momentum and time–energy, cannot be known precisely at the same time. They should know of the link between the uncertainty principle and the de Broglie hypothesis. For example, students should know that, if a particle has a uniquely defined de Broglie wavelength, then its momentum is known precisely but all knowledge of its position is lost.

13.2 Nuclear physics

	Assessment statement	Obj	Teacher's notes
13.2.1	Explain how the radii of nuclei may be estimated from charged particle scattering experiments.	3	Use of energy conservation for determining closest-approach distances for Coulomb scattering experiments is sufficient.
13.2.2	Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer.	2	Students should be able to draw a schematic diagram of the Bainbridge mass spectrometer, but the experimental details are not required. Students should appreciate that nuclear mass values provide evidence for the existence of isotopes. http://www.schoolphysics.co.uk/age16-19/Atomic%20physics/Atomic%20structure%20and%20ions/text/Mass_spectrometer/index.html

			
13.2.3	Describe one piece of evidence for the existence of nuclear energy levels.	2	For example, alpha (α) particles produced by the decay of a nucleus have discrete energies; gamma-ray (γ-ray) spectra are discrete. Students should appreciate that the nucleus, like the atom, is a quantum system and, as such, has discrete energy levels.
Radioactive decay			
13.2.4	Describe β^{+} decay, including the existence of the neutrino.	2	Students should know that β energy spectra are continuous, and that the neutrino was postulated to account for these spectra.
13.2.5	State the radioactive decay law as an exponential function and define the *decay constant*.	1	Students should know that the decay constant is defined as the probability of decay of a nucleus per unit time.
13.2.6	Derive the relationship between decay constant and half-life.	3	
13.2.7	Outline methods for measuring the half-life of an isotope.	2	Students should know the principles of measurement for both long and short half-lives. Protactinium (short half life) http://www.youtube.com/watch?v=214cwT4v3D8 Half life measurements for short half life materials can be made by plotting activity against time remembering to subtract background radiation and measuring the time taken for the activity to halve. For long half life materials the activity must be compared to the amount of nuclei present in a sample. Activity = Decay constant x Number of nuclei. Therefore the activity of the sample, the mass of the sample and the atomic mass of the isotope present in the sample must be known. As pure a sample as possible must be used.
13.2.8	Solve problems involving radioactive half-life.	3	

Topic 14: Digital technology (8 hours)

Aim 8 and **Int:** This topic shows how technological advances involving many different applications are based on fundamental physics. The implications for society of the rapid pace of technological innovation can be discussed.

14.1 Analogue and digital signals

4 hours

	Assessment statement	Obj	Teacher's notes
14.1.1	Solve problems involving the conversion between binary numbers and decimal numbers.	3	Students should be aware of the term bit. An awareness of the least-significant bit (LSB) and most-significant bit (MSB) is required. Problems will be limited to a maximum of five bits in digital numbers.
14.1.2	Describe different means of storage of information in both analogue and digital forms.	2	Students may consider LPs, cassette tapes, floppy disks, hard disks, CDs, DVDs, and so on.
14.1.3	Explain how interference of light is used to recover information stored on a CD.	3	Students must know that destructive interference occurs when light is reflected from the edge of a pit.
14.1.4	Calculate an appropriate depth for a pit from the wavelength of the laser light.	2	
14.1.5	Solve problems on CDs and DVDs related to data storage capacity.	3	
14.1.6	Discuss the advantage of the storage of information in digital rather than analogue form.	3	Students should consider quality, reproducibility, retrieval speed, portability of stored data and manipulation of data.
14.1.7	Discuss the implications for society of ever-increasing capability of data storage.	3	Teachers should consider moral, ethical, social, economic and environmental implications.

14.2 Data capture; digital imaging using charge-coupled devices (CCDs)

4 hours

	Assessment statement	Obj	Teacher's notes
14.2.1	Define *capacitance*.	1	
14.2.2	Describe the structure of a charge-coupled device (CCD).	2	Students should know that a CCD is a silicon chip divided into small areas called pixels. Each pixel can be considered to behave as a capacitor.
14.2.3	Explain how incident light causes charge to build up within a pixel.	3	Students are required to use the photoelectric effect.
14.2.4	Outline how the image on a CCD is digitized.	2	Students are only required to know that an electrode measures the potential difference developed across each pixel and this is then converted into a digital signal. The pixel position is also stored.
14.2.5	Define *quantum efficiency* of a pixel.	1	Quantum efficiency is the ratio of the number of photoelectrons emitted to the number of photons incident on the pixel.
14.2.6	Define *magnification*.	1	Students are required to know that magnification is the ratio of the length of the image on the CCD to the length of the object.
14.2.7	State that two points on an object may be just resolved on a CCD if the images of the points are at least two pixels apart.	1	
14.2.8	Discuss the effects of quantum efficiency, magnification and resolution on the quality of the processed image.	3	
14.2.9	Describe a range of practical uses of a CCD, and list some advantages compared with the use of film.	2	Students should appreciate that CCDs are used for image capturing in a large range of the electromagnetic spectrum. They should consider items such as digital cameras, video cameras, telescopes, including the Hubble Telescope, and medical X-ray imaging.
14.2.10	Outline how the image stored in a CCD is retrieved.	2	
14.2.11	Solve problems involving the use of CCDs.	3	

Options

Students at SL are required to study any **two** options from A–G.
The duration of each option is 15 hours.

Students at HL are required to study any **two** options from E–J.
The duration of each option is 22 hours.

A-D SL only Options

Option	Same as
Option A: Sight and wave phenomena	11.1-11.5
Option B: Quantum physics and nuclear physics	13.1-13.2
Option C: Digital technology	14.1-14.2, F5-F6
Option D: Relativity and particle physics	H1-H3, J1 and J3

E-G SL & HL Options

SL students study the core of these options and HL students study the whole option (the core and the extension material).

Option E: Astrophysics (15/22 hours)

SL students study the core of these options and HL students study the whole option (the core and the extension material).

The European Space Agency web site contains material specifically written for this option (see OCC for details).

Aim 7: This option allows great scope for the use of ICT. Databases of astronomical data may be assessed, and simulations depicting astronomical processes may be used in teaching and learning. Spreadsheets may be used to model astronomical events. The web sites of large space organizations contain much useful material.

Aim 8: The ethical implications of the cost of space research may be discussed.

Int: These web sites can also be used to illustrate the international nature of collaboration and research in terms of, for example, telescopes and spacecraft missions.

TOK: This option also allows for much discussion of scientific theories (on the nature and origin of the universe) and how those theories are developed and accepted or abandoned.

Core material: E1–E4 are core material for SL and HL (15 hours).

Extension material: E5–E6 are extension material for HL only (7 hours).

E1 Introduction to the universe

2 hours

<table>
<tr><th></th><th>Assessment statement</th><th>Obj</th><th>Teacher’s notes</th></tr>
<tr><td colspan="4">The solar system and beyond</td></tr>
<tr><td>E.1.1</td><td>Outline the general structure of the solar system.
<table>
<tr><td>Object</td><td>Approx Distance from Sun (orbit radius)</td><td>Approx Size (diameter)</td></tr>
<tr><td>Mercury</td><td>60 million km</td><td>5000 km</td></tr>
<tr><td>Venus</td><td>0.7 AU
= 100 million km</td><td>12,000 km</td></tr>
<tr><td>Earth</td><td>1 AU
= 150 million km</td><td>13,000 km</td></tr>
<tr><td>Mars</td><td>230 million km</td><td>7,000 km</td></tr>
<tr><td>Asteroid belt</td><td>Varies</td><td>100,000 asteroids in the main belt</td></tr>
<tr><td>Jupiter</td><td>5.2 AU</td><td>140,000 km</td></tr>
<tr><td>Saturn</td><td>9.5 AU</td><td>120,000 km</td></tr>
</table></td><td>2</td><td>Students should know that the planets orbit the Sun in ellipses and moons orbit planets. (Details of Kepler’s laws are not required.) Students should also know the names of the planets, their approximate comparative sizes and comparative distances from the Sun, the nature of comets, and the nature and position of the asteroid belt.

In the Solar system centre we have the sun, our closest star. There are so far 9 known planets, of which the 5 inner have been known since ancient times, Uranus was discovered in the 18th and Neptune in the 19th century, Pluto as late as 1930. The gravitational disturbances on the orbits of the outermost planets have led to successful predictions of the existence and approximate orbits of new ones. Irregularities in the orbit of Mercury (its</td></tr>
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<table>
<tr>
<td></td>
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<table>
<tr><td>Uranus</td><td>18 AU
= 2.7 billion km</td><td>50,000 km</td></tr>
<tr><td>Neptune</td><td>19 AU
= 2.8 billion km</td><td>50,000 km</td></tr>
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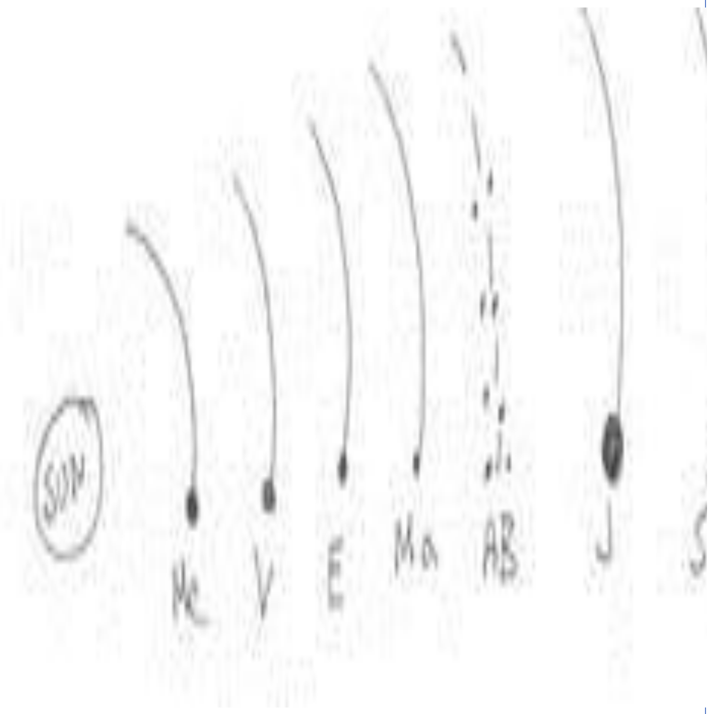
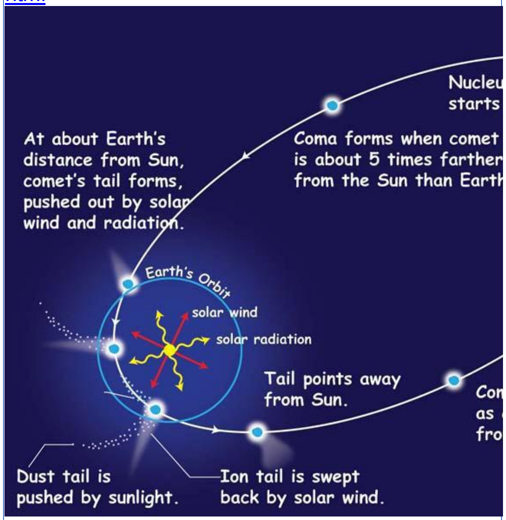


</td>
<td></td>
<td>'perihelium precession') led in the late 19th century to a search for a planet even closer to the sun (and it was tentatively named Vulcan) but none was found and the irregularities ~ 1915 shown to be a side-effect of the theory of relativity.

The average distance of Earth from the sun, ~ 150 million km or 1.5 x 1011 m is called 1 astronomical unit, 1 AU. The mass of the earth is ~ 6 x 1024 kg. The radius of earth is ~ 6370 km.

http://library.thinkquest.org/25401/data/text/planets.html


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<tr>
<td>E.1
.2</td>
<td>Distinguish between a stellar cluster and a constellation.</td>
<td>2</td>
<td>In some parts of a galaxy a number (maybe 100 - 10000) stars can be considerably closer to each other than the several lightyears common in our parts of the galaxy. These are stellar clusters.

A constellation is a pattern of stars which seem to be near each other in the night sky. In 3-dimensional reality they do not have to be near each other.</td>
</tr>
<tr>
<td>E.1
.3</td>
<td>Define the light year.</td>
<td>1</td>
<td>For distances within the solar system, the astronomical unit is suitable. Outside that the light year (ly), is used. This is the distance travelled by light in one year (= 60 x 60 x 24 x 365 seconds = 31,536,000s) so

1 ly = 3.00 x 108 ms-1 x 31,536,000s = 9.46 x 1015 m

The nearest stars are ~ 4 ly (Alpha Centauri, a triple star) and 6 ly (Barnard's star) from us. For comparison, Earth is about 8 light minutes from the sun; Pluto about 6 light hours.</td>
</tr>
<tr>
<td>E.1
.4</td>
<td>Compare the relative distances between stars within a galaxy and between galaxies, in terms of order of magnitude.</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>E.1
.5</td>
<td>Describe the apparent motion of the stars/constellations over a period of a night and over a period of a year, and explain these observations in terms of the rotation and revolution of the Earth.</td>
<td>3</td>
<td>Daily motion: As the earth rotates once every 24 hours the stars seem to rotate while keeping their positions relative to each other. In a direction where an axis can be imagined to go from the south pole to the north pole and onwards one will find the point in the sky which stars seem to rotate in circles around. Very near to this direction the star Polaris is found.</td>
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</table>

			Annual motion: As the earth makes a revolution around the sun the set of stars visible above the horizon changes somewhat during the year since the earths imagined axis is not at a perfect 90o angle to the plane of revolution, but rather at one of ~ 66.5o (in other words - a plane through the equator makes a 23.5o angle with the plane of revolution). This is the basic background for stellar parallax. Other observations, for example, seasons and the motion of planets, are not expected.

E2 Stellar radiation and stellar types

4 hours

	Assessment statement	Obj	Teacher's notes
Energy source			
E.2.1	State that fusion is the main energy source of stars.	1	Students should know that the basic process is one in which hydrogen is converted into helium. They do not need to know about the fusion of elements with higher proton numbers.
E.2.2	Explain that, in a stable star (for example, our Sun), there is an equilibrium between radiation pressure and gravitational pressure.	3	
Luminosity			
E.2.3	Define the *luminosity* of a star.	1	measure of the radiant power emitted by an object (for example a star) **absolute luminosity L** for the power in W of (the light emitted by) a star
E.2.4	Define *apparent brightness* and state how it is measured.	1	intensity of the radiation from an object as measured from Earth (how much flux is coming from the star per square meter per second, as measured on Earth) **apparent brightness b** for the intensity in Wm^{-2} of the starlight which hits an observer on earth, at a distance now called d so: $\mathbf{b = L / 4\pi r^2}$
Wien's law and the Stefan–Boltzmann law			
E.2.5	Apply the Stefan–Boltzmann law to compare the luminosities of different stars.	2	*Stefan-Boltzmann's law ("the hotter, the more power is radiated")* By studying various objects in laboratories on earth their temperature T and power of radiation P (or here luminosity L) can be measured it is found that the Stefan-Boltzmann law holds: L = σAT4 [Data Book p. 12] where Stefan-Boltzmann constant σ = 5.67 x 10-8 Wm-2K-4 [in Data Book] and A = the surface area of the object. (Strictly, this formula is valid for a "black body", one that emits and absorbs radiation perfectly. For a shiny object like a thermos can one would have to include

another factor, the emissivity, which would be 1 for a "black body" and between 0 and 1 for others. It turns out that hot gases have emissivities close to 1).

We could then get a value for L if we

- assume that the same physics is valid for a star far away from us as for the objects in our lab
- find out the surface temperature T of the star (without actually travelling there and sticking a thermometer into it)
- find a value for its surface area A

In order to find $L = \sigma AT^4$ (which together with the measured b-value can give us the distance d from $b = L / 4\pi d^2$) we still need the surface area A. We assume that the star is shaped like a sphere so if we find its volume $V = (4/3)\pi r^3$ we can get the radius of the star r and then its surface $A = 4\pi r^2$ (Notice the conceptual difference between the surface area of a spherical radiation source and the imagined sphere at a distance d from the source - or strictly the centre of the source - over which its inner imagined surface its radiation is spread) or vice versa. This method of relating distance d, apparent brightness b, absolute luminosity L, surface temperature T and peak wavelength λ_{max} is primarily therefore not used to find the distance of stars very far away, but to find out more (e.g. the size of) about those near enough for the parallax method for finding the distance to work. A summary of other distance measuring methods will come later, first we will turn to what more one can learn about a star by observing the light from it.

E.2.6	State Wien's (displacement) law and apply it to explain the connection between the colour and temperature of stars.	2

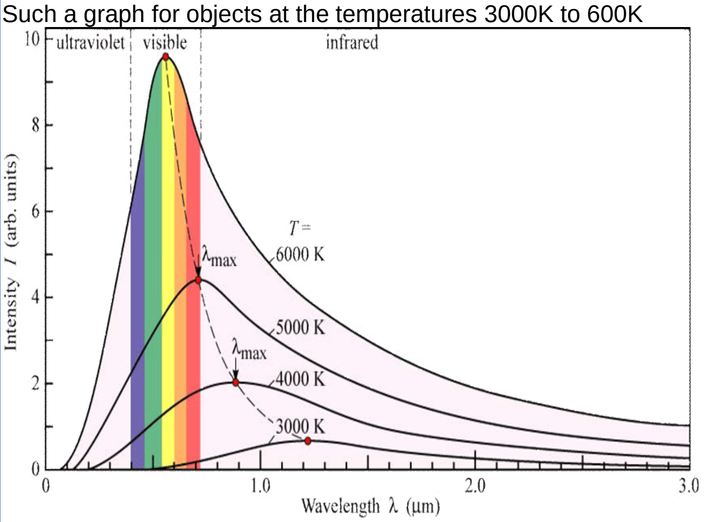
Wien's displacement law ("the colour changes with temperature")

Black-body radiation

The study of black-body radiators (which also caused Planck ~ 1900 to first suggest that the energy of a photon of light or other electromagnetic radiation to be $E = hf$, later confirmed by Einstein's analysis of the photoelectric effect) gave among other results a number of curves of how much radiation was emitted at different wavelengths for objects at various surface temperatures.

Wien's displacement law

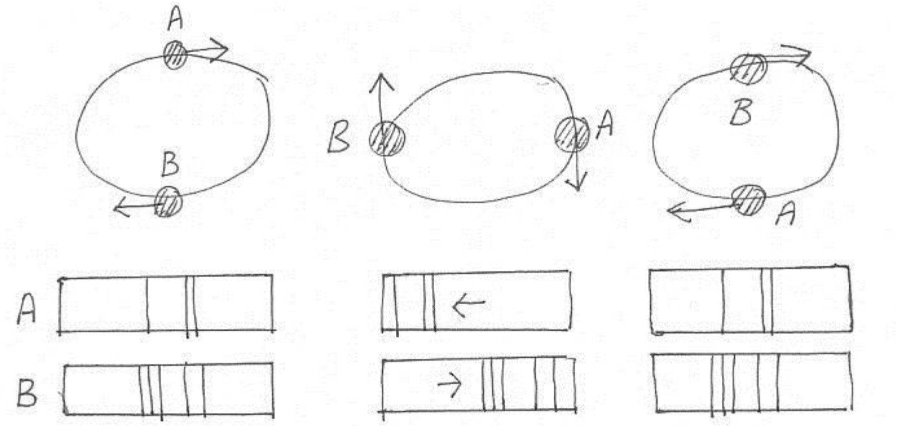
Such a graph for objects at the temperatures 3000K to 600K



It can be noted that the peak of the curve will shift (be "displaced") along a graph indicated by the dotted line. If one were to make a graph of this peak wavelength, λ_{max} , as a function of surface temperature T one would find that it follows a hyperbolic graph (similar to $y = 1/x$ or generally $y = k/x$) giving "Wien's displacement law"

$\lambda_{max} = 2.90 \times 10^{-3} / T$	[Data Book p. 12]

			The constant in Wien's displacement law is sometimes called for short "Wien's constant" and should be assigned units: 2.90 x 103 Km (kelvinmetres). It is rarely given any symbol, but one can be assigned to it at will. This law means that the hotter something gets, the shorter the wavelength (or the higher the frequency) of the electromagnetic radiation it emits most of. We will notice this as a change in colour: if you heat up a piece of iron it will first look like it did before heating (but emit invisible infrared radiation, observable in a "heat camera"), then become red-glowing (red has the longest wavelength of visible light), then white-glowing (indicating that also other, shorter, wavelengths are emitted) and eventually blue-glowing (but iron would have melted and been vaporised before that). Applied to starlight this means that if we can find out the peak wavelength λmax of a star's light then we can say what its surface temperature T is. (One would fit the telescope with different colour filters to find out what type of light is dominant).
Stellar spectra			
E.2.7	Explain how atomic spectra may be used to deduce chemical and physical data for stars.	3	Students must have a qualitative appreciation of the Doppler effect as applied to light, including the terms red-shift and blue-shift. **Stellar spectra and chemical composition** Information from the spectra and spectral classes Light is produced in nuclear fission reactions deep in the core of a star (see later) and is absorbed and re-emitted many times on its way out to the surface, and therefore has a rather continuous distribution of wavelengths. Chemical elements, ions and molecules near the surface will cause absorption lines in the spectrum (missing wavelengths) which provide information about the elements that exist in a star. As well as the hydrogen and helium (the input and output of the main fission reaction) traces of several other elements are found, and these are typical for stars of different surface temperatures. (It may be noted that the spectral line of the element helium was found in sunlight before helium had been found on earth. The element was given its name for an ancient Greek sun "god", Helios, and was later also detected in small amounts in the atmosphere).
E.2.8	Describe the overall classification system of spectral classes.	2	The types of stars have been divided into spectral classes (the Harvard system) which for some unknown reason have been assigned the letters O, B, A, F, G, K and M (which can be remembered with the phrase Oh, Be A Fine Girl, Kiss Me.) Spectral class Surface temperature Colour Typical spectral lines O 20,000-35,000 K blue He- and other ions B ~ 15,000 K blue-white Neutral He A ~ 9,000 K white Neutral H, metals F ~ 7,000 K white-yell. metal ions G ~ 5,500 K yellow K, CN-, Ca-ions K ~ 4,000 K orange metals, TiO M ~ 3,000 K red TiO The temperature intervals and typical spectral lines vary in the literature. The classes are further divided with numbers (G0, G1, ..., G9, K1, K2, ...) and there are some other classes for types of stars with other properties. Our sun is a yellow G-class star with a surface temperature of ~ 5,800 K.
Types of star			
E.2.9	Describe the different types of star.	2	Students need to refer only to single and binary stars, Cepheids, red giants, red supergiants and white dwarfs. Knowledge of different types of Cepheids is not required. *Pulsars and quasars* In the 1960s objects which emit light or other radiation in regular pulses were discovered and first briefly considered possible signs of extra-terrestrial life. They are more likely to be stars which emit radiation dominantly in one direction, which because of the star's rotation make them appear as regularly flashing beacons, pulsating stars or pulsars. Certain stars emit much more radiation than a star regularly does and are named quasistellar objects or quasars.

			Variable stars and Cepheids Most stars, including our sun, have periodically varying brightness or intensity. For some stars (e.g. Cepheids) the periodic variations in intensity are clearer and related to the "power" with which it emits light and other types of radiation. This will prove useful in the later sections.
E.2.10	Discuss the characteristics of spectroscopic and eclipsing binary stars.	3	*Binary stars* Many stars are not, like our sun, the only one in a solar system. It is quite common for a star to be a double (binary) or triple star, that is to have two or three stars rotating around each other or some point in space. In such a solar system it could be difficult to have as stable a planetary orbit, and even more difficult to have one in which the planet remains at roughly the same distance from a star providing a stable climate. Binary stars can be categorized as: - visual binaries: a double star where the two components can be distinguished with a strong telescope - spectroscopic binaries: a double star which appears to be one star, but where the spectral lines emitted change wavelength because of the Doppler effect (see diagram below)  - eclipsing binaries : a double star detected as such by one star getting in the way of the other thus decreasing its brightness temporarily (not to be confused with a variable star, see below) In addition to these there can be false (visual) binaries which appear to be very close but may be at very different distances from us.
The Hertzsprung–Russell diagram			
E.2.11	Identify the general regions of star types on a Hertzsprung–Russell (HR) diagram.	2	Main sequence, red giant, red supergiant, white dwarf and Cepheid stars should be shown, with scales of luminosity and/or absolute magnitude, spectral class and/or surface temperature indicated. Students should be aware that the scale is not linear. Students should know that the mass of main sequence stars is dependent on position on the HR diagram. Note that we have: • horizontal axis: the spectral classes O,B,A,F,G,K and M so **the temperature decreases from left to right** • vertical axis: the **luminosity (power) on a logarithmic scale** using either the value in watts or as in how many times the power of the sun a stars luminosity is. $L_{sun} = 3.9 \times 10^{26}$ W. :

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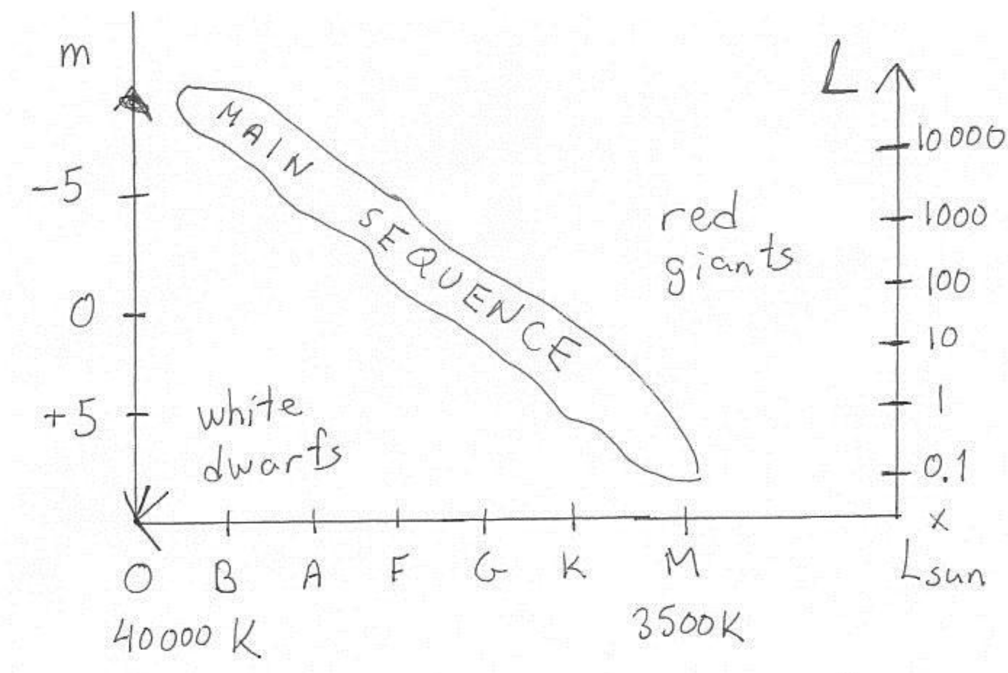
<tr><td></td><td></td><td></td><td>

In the graph we notice these features:
The main sequence, most stars are placed along a band roughly from the upper left to the lower right corner of the H-R-diagram
red giants, stars with a low temperature (would be class K or M) but a much higher luminosity than main sequence stars which means the size must be bigger (recall $L = \sigma AT4$, same T but bigger L requires bigger surface area A). They are in the upper right corner of the H-R.
white dwarfs, hot stars with a lower L -> smaller size than the main sequence; in the lower left corner of the H-R.
The red giants and white dwarfs differ from the main sequence stars also in their chemical composition and are temporary phases near the end of a star's "life"</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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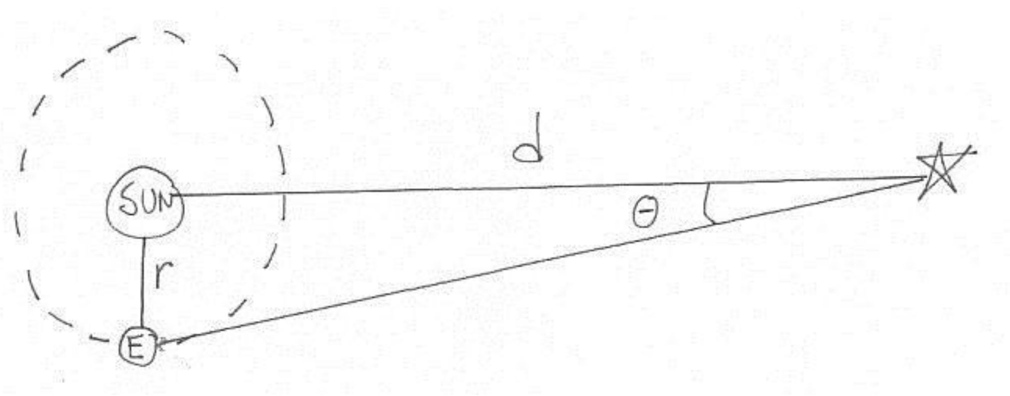
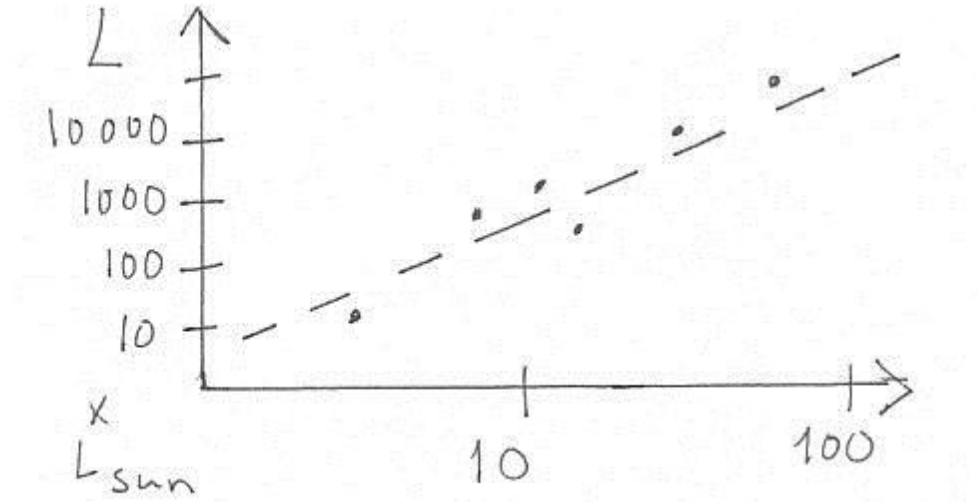
E3Stellar distances

5 hours

	Assessment statement	Obj	Teacher's notes
Parallax method			
E.3.1	Define the *parsec*.	1	
E.3.2	Describe the stellar parallax method of determining the distance to a star.	2	**Stellar parallax** When the earth makes a revolution around the sun in one year, other stars (rather near us) will appear to be in a slightly different direction (compared to a background of stars very far away). This enables the angle θ, described in the diagram below, to be measured – this is called the parallax angle. This angle is very small, and often measured in the unit 1 arcsecond = 1/3,600 of a degree.

			 From this we find that: - $\tan \theta = r / d \Rightarrow d = r / \tan \theta$ but since $\tan \theta \approx \theta$ for very small θ (in radians) we get - $d = r / \theta$ If we here used conventional SI units we would insert r in metres, θ in radians and get d in metres. If instead we use AU for r (which gives r = 1 in this unit), arc-seconds for θ which we now call p (for parallax angle) then the value obtained for d will by definition be in a unit called 1 parsec = 1 pc, where **1 parsec = 3.26 ly** **d(parsec) = 1 / p(arc-second)** Since there is a limit to the "resolution" of telescopes, that is how small an angle they can measure, this method is relevant only for stars rather near us, currently up to about 100 pc (~ 300 ly). Within this distance there are, however, a number of stars which can be used to check the validity of other distance measurement methods (recall that the nearest star is ~ 4 ly from us; the 20 nearest are within ~ 12 ly).
E.3.3	Explain why the method of stellar parallax is limited to measuring stellar distances less than several hundred parsecs.	3	Measurements made from Earth have atmospheric turbulence and distances of approximately 100pc are measurable accurately. The Hipparcos satellite can do ten times better than this and can measure parallax well for distances up to 1000pc http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit1/distances.html
E.3.4	Solve problems involving stellar parallax.	3	
Absolute and apparent magnitudes			
E.3.5	Describe the apparent magnitude scale.	2	Students should know that apparent magnitude depends on luminosity and the distance to a star. They should also know that a magnitude 1 star is 100 times brighter than a magnitude 6 star. The intensity values of starlight are extremely small and historically the intensity or brightness of stars was first described, based on mere visual observations, by dividing stars into a magnitude of class 1 (the brightest), magnitude 2 (not so bright) etc to magnitude 6 (just barely visible for the naked eye) To connect the intensity value in a more mathematically precise way a logarithmic scale has been developed to fit the historical scale as closely as possible. To fit the historical scale in modern measurements it turns out that a magnitude 1 star had an apparent brightness (intensity) about 100 times greater than a magnitude 6 star.

			i.e a reduction in apparent by a value 5 means an increase in brightness by a factor of 100.
E.3.6	Define *absolute magnitude*.	1	Absolute magnitude is equal to the apparent magnitude of a star as it would appear to a hypothetical observer at a distance of 10 parsecs.
E.3.7	Solve problems involving apparent magnitude, absolute magnitude and distance.	3	
E.3.8	Solve problems involving apparent brightness and apparent magnitude.	3	
Spectroscopic parallax			
E.3.9	State that the luminosity of a star may be estimated from its spectrum.	1	
E.3.10 E.3.11	Explain how stellar distance may be determined using apparent brightness and luminosity. State that the method of spectroscopic parallax is limited to measuring stellar distances less than about 10 Mpc.	3 1	Spectroscopic parallax The basic features of the H-R can be found using the population of stars near enough for the parallax method for distance measurement. Making the assumption that stars far away have the same properties as those near us, we can measure the λmax which with Wiens law gives the temperature T and observe the chemical absorption lines of a more distant star, and place it in the appropriate spectral class, or on the horizontal axis of the H-R diagram. If its chemical composition fits the main sequence stars of this class we may read an approximate L-value from the vertical axis of the H-R and together with the measured apparent brightness b we then get the distance from $b = L / 4\pi d2 \Rightarrow d = \sqrt{(4\pi b/L)}$ This method is called the spectroscopic parallax method, which is not very appropriate since it does not have anything to do with the parallax method other than that one uses it to find out the same quantity, namely the distance from us to a star. It works up to distances of about 10 Mpc = 10 million pc or ~ 30 million lightyears. Recalling that our galaxy is ~ 100,000 ly in diameter and the nearest other galaxies a few million ly away, this expands the range of distance measurements significantly more than the ~ 100 pc or 300 ly available using the parallax method.
E.3.12	Solve problems involving stellar distances, apparent brightness and luminosity.	3	

Cepheid variables			
E.3.1 3	Outline the nature of a Cepheid variable.	2	Students should know that a Cepheid variable is a star in which the outer layers undergo a periodic expansion and contraction, which produces a periodic variation in its luminosity.
E.3.1 4	State the relationship between period and absolute magnitude for Cepheid variables.	1	**Luminosity and Cepheid variables ("standard candles")** Another method of finding the luminosity L needed for a distance measurement is available from various types of variable stars, whose luminosity and intensity fluctuate periodically. The luminosity of all stars do that to some extent (for our sun, there are slight variations connected to the 11-year solar spot cycle), but for some types of stars, among which the Cepheids are best known, this variation is significant and has a regular period. By studying Cepheids near enough for a distance measurement with the parallax method and/or the "spectroscopic parallax" method (giving d, and then with a b-measurement L from $b = L / 4\pi d2 \Rightarrow L = 4\pi b d2$) the relation between L and the time period T of the fluctuation can be studied. Assuming that Cepheids further away follow the same relation as those near us, one can then measure the T, read the L off a graph like the one below and find d from $b = L / 4\pi d2$ (b, as always, can easily be measured). With powerful telescopes, individual Cepheids have been observed in other galaxies and used to determine the distance to these. 
E.3.1 5	Explain how Cepheid variables may be used as "standard candles".	3	It is sufficient for students to know that, if a Cepheid variable is located in a particular galaxy, then the distance to the galaxy may be determined.
E.3.1 6	Determine the distance to a Cepheid variable using the luminosity–period relationship.	3	

Summary of distance measurement methods

- parallax method (up to ~ 100 pc)
- spectroscopic parallax (up to 10 Mpc)
- Cepheid (standard candle) method (up to ~ 60 pc)
- other types of standard candles (up to ~ 900 Mpc)

E4Cosmology

4 hours

	Assessment statement	Obj	Teacher's notes
Olbers' paradox			
E.4.1	Describe Newton's model of the universe.	2	Students should know that Newton assumed an infinite (in space and time), uniform and static universe.
E.4.2	Explain Olbers' paradox.	3	Students should be able to show quantitatively, using the inverse square law of luminosity, that Newton's model of the universe leads to a sky that should never be dark. http://www.youtube.com/watch?v=0USMjYfkRxs (maths bit starts after 2:30)
The Big Bang model			
E.4.3	Suggest that the red-shift of light from galaxies indicates that the universe is expanding.	3	
E.4.4	Describe both space and time as originating with the Big Bang.	2	Students should appreciate that the universe is not expanding into a void.
E.4.5	Describe the discovery of cosmic microwave background (CMB) radiation by Penzias and Wilson….. In 1931 Karl Jansky used an improvised aerial to try to find the sources of interference in radio telephone links. He eventually showed that the radio emission was coming from space as he could show that one particular source crossed his aerial after 23h 56m the time taken for the Earth to rotate on its axis. He was working for Bell telephones and, once it was established that the interference was unavoidable, the subject was dropped, though others took up the subject and founded the study of radio astronomy. History repeated itself in 1965 when two Bell engineers tried to find the source of interference on the SHF band microwave links. Arno Allen Penzias and Robert Woodrow Wilson systematically worked through the whole chain of electronics and eventually decided that the signal was coming down the aerial. They even checked that out and removed the pigeons nesting nearby! Their final conclusion was that the 7.35 cm wavelength signal came from space, but they could no find any particular source. The signal seemed equally strong in all directions.	2	**Cosmic microwave background radiation** The photons (electromagnetic radiation) mentioned above increased their peak wavelength as the universe cooled and expanded. Recall wavelength = the distance between two wavecrests; if space itself between the wavecrests expands, then the wavelength increases. It should by now (as was calculated already in the 1940s) have increased so much that the radiation is in the microwave section of the EM-spectrum. It should also come from all directions, since in the early universe at 300 000 years after the Big Bang it was emitted by material in the entire universe in all directions. This cosmic microwave background (CMB) radiation was discovered by Penzias and Wilson in the 1960s and provides additional support for the Big Bang model. If the peak wavelength of the CMB is inserted in Wien's law, $\lambda max = 2.90 \times 10^{-3} / T$ it will give a value of T = ~ 3 K for the temperature of a blackbody which would emit such radiation.
E.4.6	Explain how cosmic radiation in the microwave region is consistent with the Big Bang model.	3	A simple explanation in terms of the universe "cooling down" is all that is required.
E.4.7	Suggest how the Big Bang model provides a resolution to Olbers' paradox.	3	There are several possible ways to resolve Olber's paradox. The universe may not be infinitely large or old, only very large and old (but size of the already observed universe is so large that the total

			starlight intensity should be larger than it is), or it may not be static - if the stars are moving further away from each other while the starlight is on its way, the intensity may decrease enough. One possible solution to Olber's paradox is the Big Bang model, which is also supported by other evidence outlined in the following sections.
The development of the universe			
E.4.8	Distinguish between the terms open, flat and closed when used to describe the development of the universe.	2	See below
E.4.9	Define the term *critical density* by reference to a flat model of the development of the universe.	1	See below
E.4.10	Discuss how the density of the universe determines the development of the universe.	3	See below
E.4.11	Discuss problems associated with determining the density of the universe.	3	This statement is included to give the students a flavour for the ongoing and complex current nature of research. They should be able to discuss relevant observations and possible explanations. They should recognize that, in common with many other aspects of our universe, much about the phenomena is currently not well understood. There are three possible alternatives for the future of the universe: - A : it will continue to expand forever (open universe) - B : it will continue to expand but the rate of expansion will eventually slow down to zero (flat universe) and reach a "steady state". - C : it will under the force of gravity eventually start to contract back (closed universe) into a point (Big Crunch); possibly to undergo a new Big Bang. Which of these will happen depends on the average density of the universe: if this is below a critical density, we get alternative A, if it is equal to the critical density we get B, if it is less we get C. The result depends on the existence of dark matter (invisible matter which should exist to explain the movements of visible matter in the galaxies). The whereabouts of this dark matter, which may make up as much as 90% of the mass in the universe, is currently unknown. Various suggestions of particles not yet detected have been made, such as WIMPs (Weakly Interacting Massive Particles), MACHOs (massive compact halo objects, that is dim stars or black holes difficult to observe) and others. If such dark matter exists, the universe may be flat or closed, otherwise open. http://www.astro.cornell.edu/academics/courses/astro201/q_dm.htm
E.4.12	State that current scientific evidence suggests that the universe is open.	1	
E.4.13	Discuss an example of the international nature of recent astrophysics research.	3	It is sufficient for students to outline any astrophysics project that is funded by more than one country. http://exoplanet.eu/
E.4.14	Evaluate arguments related to investing significant resources into researching the nature of the universe.	3	Students should be able to demonstrate their ability to understand the issues involved in deciding priorities for scientific research as well as being able to express their own opinions coherently.

E5 Stellar processes and stellar evolution

4 hours

	Assessment statement	Obj	Teacher's notes
Nucleosynthesis			
E.5.1	Describe the conditions that initiate fusion in a star.	2	
E.5.2	State the effect of a star's mass on the end product of nuclear fusion.	1	

E.5.3	Outline the changes that take place in nucleosynthesis when a star leaves the main sequence and becomes a red giant.	2	Students need to know an outline only of the processes of helium fusion and silicon fusion to form iron.

Evolutionary paths of stars and stellar processes

The "life" of a star

"Birth"

Wherever there is a large cloud (nebula) of hydrogen in the universe, gravity will make it contract and get denser and hotter. If it is large enough, it will first form a protostar which is glowing (sometimes brighter than the later "real" star it will become) because of the high temperature. If the temperature and pressure in the centre of the protostar become high enough, fusion reactions ignite and the star enters the main sequence in the H-R-diagram. Where on the main sequence it appears (what spectral class it will have) depends primarily on its mass - the greater the mass, the hotter.

"Life" in the main sequence

The more massive the star is, the faster will it change from a nebula to a star (~ 10,000 years for very heavy stars, 10 million years for smaller) and the faster will it burn up its hydrogen fuel and reach the end of its "life" (a few hundred million years for big stars, several billion for smaller. Our sun has been around for ~ 5 billion years and is expected to last for several more).

The "death" of a star

When the fusion reactions in the core of a star run out of hydrogen the outward radiation pressure decreases and the equilibrium that was in place during its "life" in the main sequence is disturbed - the star collapses under the force of gravity. This will however bring more fresh hydrogen fuel in towards the centre and the fusion reactions will temporarily increase again. The radiation pressure pushes out the outer layers of the star so that its size increases dramatically (the sun is expected to "swallow" the inner planets when this happens) but the surface temperature drops and the colour following Wien's displacement law changes. The star now becomes a red giant or supergiant depending on its mass.

Nucleosynthesis

Already in the main sequence the fusion reactions involved more than just hydrogen and helium, but during the final stages of the star's "life" more nuclear reactions (e.g. He undergoing fusion to Si and onwards to Fe) take place when the pressure and temperature is higher, forming heavier elements. These are in subsequent phases spread out in the universe and believed to eventually end up (possibly via the life of another star on planets), including into us. The iron atoms in your blood cells were most likely produced inside a star far away from here billions of years ago.

The Chandrasekhar limit

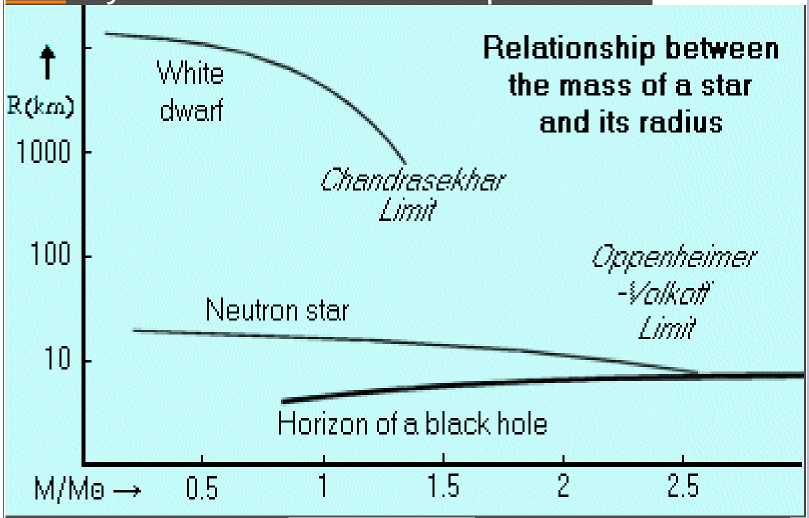
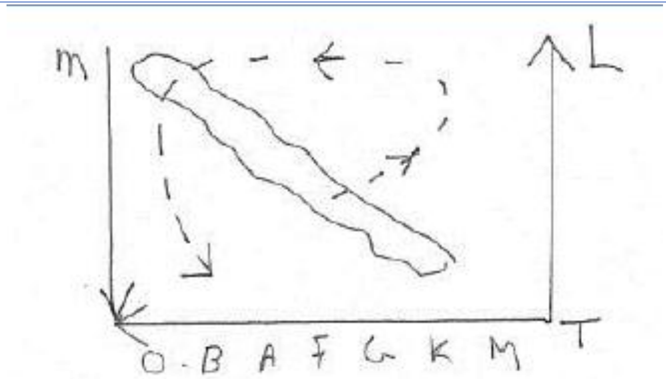
What happens now depends on the mass of the star, expressed in how many times the mass of our sun its, msun :

- if m < 1.4msun , then the star becomes a red giant and then a white dwarf, a small but hot and shortlived star which when it runs out of all possible fusion fuel becomes a "brown" or "black" dwarf, a lump of material sitting in space and not doing anything special. See H-R diagram below.
- if 1.4msun (the Chandrasekhar limit) < m < 8msun , then the star will first become a red supergiant, then as this collapses and material falls quickly towards the centre have a very violent explosion called a nova or supernova. Such an explosion lasts for only a few years or decades. The leftovers then contract so much that the quantum mechanical rules for how many electrons can be packed close together are overcome, electrons and protons form neutrons, and the star becomes a neutron star. The stars called pulsars may be a type of neutron stars.
- if m > 8msun the star will become first a red supergiant and then a supernova as above, but eventually collapse to a black hole, see later section.

Black holes

One possible final fate of a star is to become a black hole from which nothing, including light, can escape (other than by a quantum-mechanical type of "evaporation", not needed to know here)

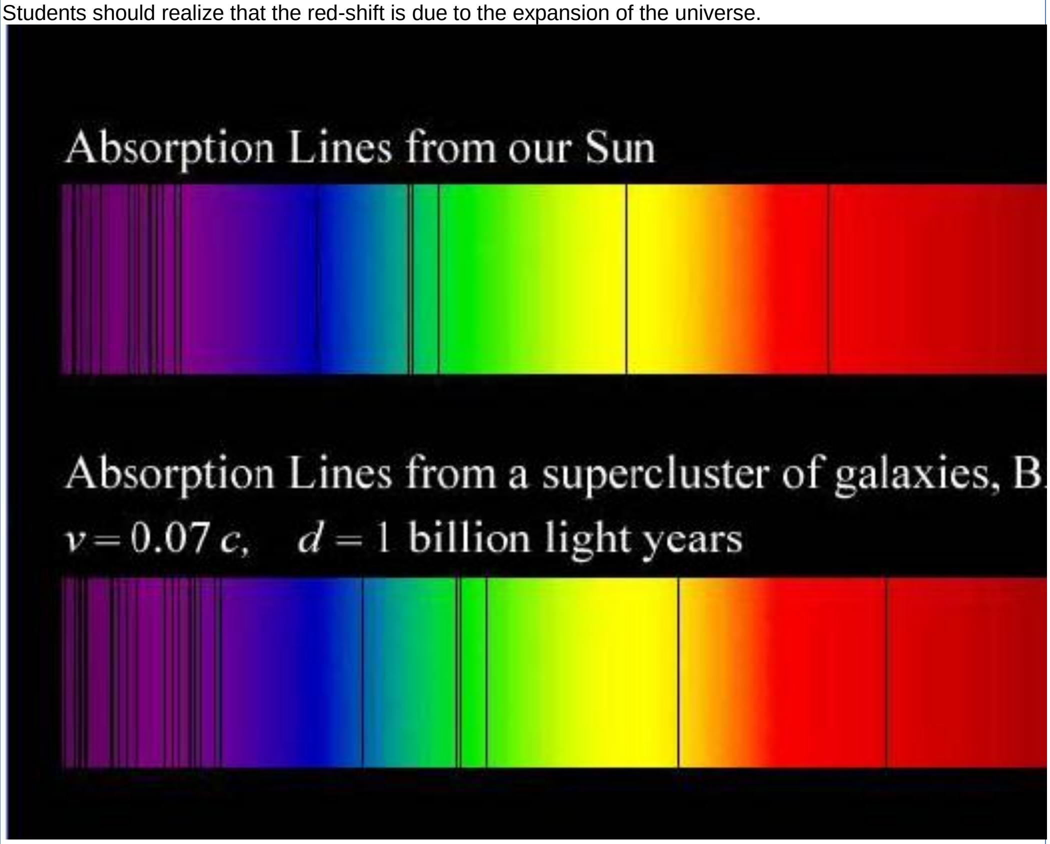
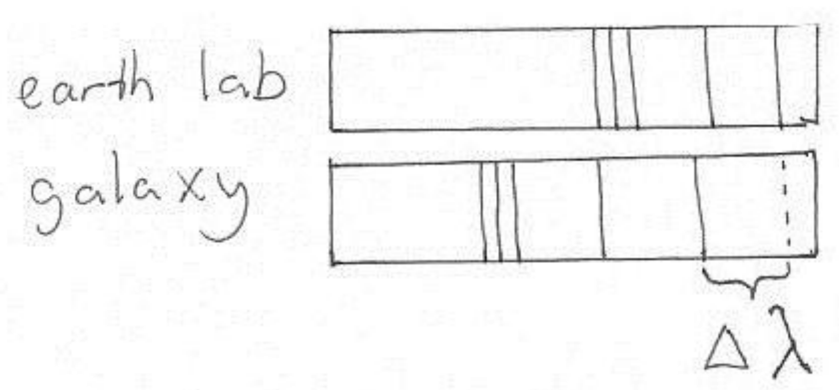
E.5.4	Apply the mass–luminosity relation.	2	$L = M^n$ (see data booklet)
E.5.5	Explain how the Chandrasekhar and Oppenheimer–Volkoff limits	3	**Oppenheimer-Volkoff limit**

	are used to predict the fate of stars of different masses.		The upper limit for the mass of a neutron starbeyond which it must collapse to bec  ome a black hole or, possibly, a quark star. Its value is not known exactly because the properties of neutrondegenerate matter can only be estimated, but it is generally thought to be between 2 and 3 solar masses.
E.5.6	Compare the fate of a red giant and a red supergiant.	3	Students should know that: • a red giant forms a planetary nebula and then becomes a white dwarf • a white dwarf is stable due to electron degeneracy pressure • a red supergiant experiences a supernova and becomes a neutron star or collapses to a black hole • a neutron star is stable due to neutron degeneracy pressure.
E.5.7	Draw evolutionary paths of stars on an HR diagram.	1	
E.5.8	Outline the characteristics of pulsars.	2	A **pulsar** (portmanteau of *pulsating star*) is a highly magnetized, rotating neutron starthat emits a beam of electromagnetic radiation. This radiation can only be observed when the beam of emission is pointing toward the Earth, much the way a lighthouse can only be seen when the light is pointed in the direction of an observer, and is responsible for the pulsed appearance of emission. Neutron stars are very dense, and have short, regular rotational periods. This produces a very precise interval between pulses that range from roughly milliseconds to seconds for an individual pulsar.

E6 Galaxies and the expanding universe

3 hours

	Assessme	Ob	Teacher's notes

	nt statement	j	
Galactic motion			
E.6.1	Describe the distribution of galaxies in the universe.	2	Students should understand the terms galactic cluster and galactic supercluster.
E.6.2	Explain the red-shift of light from distant galaxies.	3	Students should realize that the red-shift is due to the expansion of the universe. 
E.6.3	Solve problems involving red-shift and the recession speed of galaxies.	3	Use *fractional change in wavelength x c* to get recession velocity. $\Delta\lambda / \lambda \approx v / c$ ➔ $v \approx c\Delta\lambda / \lambda$ 
Hubble's law			
E.6.4	State Hubble's law.	1	**Hubble's law** is the observation that: (1) all objects observed in deep space (intergalactic space) are found to have a Doppler shift observable relative velocity to Earth, *and* to each other; and (2) that this Doppler-shift-measured velocity, of various galaxies receding from the Earth, is proportional to their distance from the

			Earth and all other interstellar bodies. In effect, the space-time volume of the observable universe is expanding.
E.6.5	Discuss the limitations of Hubble's law.	3	Hubble constant is a gradient taken from approximate measurements and these measurements do not all fit the gradient precisely. Recession velocity may not be constant.
E.6.6	Explain how the Hubble constant may be determined.	3	*Hubble's law* We are now able to measure and conclude the following for the **galaxies** of the universe: • their **distance d** from us, for galaxies primarily using Cepheid standard candles • their **recession speed v** from the spectral redshift It turns out that the relation between these is linear and follows **Hubble's law:** **v = Hd** where the Hubble constant H which due to large uncertainties in the distance measurements for galaxies very far away is somewhere between 40 and 100 kms^{-1}(Mpc)$^{-1}$. Hubble's law means that other galaxies are moving away from us (and/or we from them) and do so faster the further away they are. This supports the **Big Bang** model.
E.6.7	Explain how the Hubble constant may be used to estimate the age of the universe.	3	*The Hubble constant and the age of the universe* Assuming that the Hubble constant has been the same over time, one can find a value for the age of the universe from Hubble's law. • Let us take an arbitrary galaxy and find the time t it took for it to recede away from us to its present distance d • if **v was constant**, then v = d/t or t = d/v • but now v = Hd so we get t = d / Hd or • $\mathbf{t_{universe} = 1 / H}$ This time is the same for all galaxies and indicates how long ago they all - the whole visible universe - was packed closely in one place. Ex. Let H = 80 kms^{-1}(Mpc)$^{-1}$. Then 1/H = 1 Mpc/ 80kms^{-1} = (1000 000 x 3.26 ly) / 80 000 ms^{-1} = 100 x 3.26 x 9.46 x 10^{15} / 8 ms^{-1} = 3.85 x 10^{17} s; using that one year is 60x60x24x365 s = 31,536,000s which is about 3 x 10^{7} years we get about (3.85 x 10^{17}/3 x 10^{7}) years or ~ 13,000 million years, 13 billion years. Different H-values give ages of the universe usually between 10 and 20 billion years.
E.6.8	Solve problems involving Hubble's law.	3	
E.6.	Explain how	3	Students should appreciate that, at the very high temperatures of the early universe, only elementary

9	the expansion of the universe made possible the formation of light nuclei and atoms.		(fundamental) particles could exist and that expansion gave rise to cooling to temperatures at which light nuclei could be stable.

Slide show giving review of main astrophysics ideas

http://www.slideshare.net/nothingnerdy/astrophysics-stellar-distances?utm_source=slideshow02&utm_medium=ssemail&utm_campaign=share_slideshow

Option F: Communications (15/22 hours)

SL students study the core of these options and HL students study the whole option (the core and the extension material).

Core material: F1–F4 are core material for SL and HL (15 hours).

Extension material: F5–F6 are extension material for HL only (7 hours).

F1Radio communication

5 hours

	Assessment statement	Obj	Teacher's notes
F.1.1	Describe what is meant by the modulation of a wave.	2	Students should appreciate that, for information to be carried by a wave, the wave must be changed in some way.
F.1.2	Distinguish between a carrier wave and a signal wave.	2	
F.1.3	Describe the nature of amplitude modulation (AM) and frequency modulation (FM).	2	For both AM and FM, students should appreciate how the carrier wave is modified in order to transmit the information in the signal wave.
F.1.4	Solve problems based on the modulation of the carrier wave in order to determine the frequency and amplitude of the information signal.	3	
F.1.5	Sketch and analyse graphs of the power spectrum of a carrier wave that is amplitude-modulated by a single-frequency signal.	3	
F.1.6	Define what is meant by *sideband frequencies* and *bandwidth*.	1	
F.1.7	Solve problems involving sideband frequencies and bandwidth.	3	
F.1.8	Describe the relative advantages and disadvantages of AM and FM for radio transmission and reception.	2	Students should consider quality, bandwidth, range and cost.
F.1.9	Describe, by means of a block diagram, an AM radio receiver.	2	Students should be able to identify and describe the function of each block, including aerial and tuning circuit, RF amplifier, demodulator, AF amplifier and loudspeaker.

F2Digital signals

4 hours

	Assessment statement	Obj	Teacher's notes
F.2.1	Solve problems involving the conversion between binary numbers and decimal numbers.	3	Students should be aware of the term bit. An awareness of the least-significant bit (LSB) and most-significant bit (MSB) is required. Problems will be

			limited to a maximum of five bits in digital numbers.
F.2.2	Distinguish between analogue and digital signals.	2	
F.2.3	State the advantages of the digital transmission, as compared to the analogue transmission, of information.	1	
F.2.4	Describe, using block diagrams, the principles of the transmission and reception of digital signals.	2	Students should be able to name and give the function of each block, including sample-and-hold, clock, analogue-to-digital converter (ADC), parallel-to-serial converter, serial-to-parallel converter and digital-to-analogue converter (DAC).
F.2.5	Explain the significance of the number of bits and the bit-rate on the reproduction of a transmitted signal.	3	
F.2.6	Describe what is meant by time-division multiplexing.	2	
F.2.7	Solve problems involving analogue-to-digital conversion.	3	
F.2.8	Describe the consequences of digital communication and multiplexing on worldwide communications.	2	Students should be able to discuss cost and availability to the general public, quality of transmission, and the development of means of communication and data sharing such as the Internet.
F.2.9	Discuss the moral, ethical, economic and environmental issues arising from access to the Internet.	3	

F3Optic fibre transmission

3 hours

	Assessment statement	Obj	Teacher's notes
F.3.1	Explain what is meant by critical angle and total internal reflection.	3	
F.3.2	Solve problems involving refractive index and critical angle.	3	
F.3.3	Apply the concept of total internal reflection to the transmission of light along an optic fibre.	2	Only step-index optic fibres are to be considered.
F.3.4	Describe the effects of material dispersion and modal dispersion.	2	Students should appreciate the effects of dispersion on the frequency of pulses that can be transmitted and the development of step-index monomode fibres.
F.3.5	Explain what is meant by attenuation and solve problems involving attenuation measured in decibels (dB).	3	
F.3.6	Describe the variation with wavelength of the attenuation of radiation in the core of a monomode fibre.	2	Students should be familiar with attenuation per unit length measured in dB km^{-1}. Specific values of attenuation are not required.
F.3.7	State what is meant by noise in an optic fibre.	1	
F.3.8	Describe the role of amplifiers and reshapers in optic fibre transmission.	2	Students should appreciate that reshaping of digital signals being transmitted along an optic fibre reduces the effects of noise.
F.3.9	Solve problems involving optic fibres.	3	

F4Channels of communication

3 hours

	Assessment statement	Obj	Teacher's notes
F.4.1	Outline different channels of communication, including wire pairs, coaxial cables, optic fibres, radio waves and satellite communication.	2	
F.4.2	Discuss the uses and the relative advantages	3	Students should include noise, attenuation,

	and disadvantages of wire pairs, coaxial cables, optic fibres and radio waves.		bandwidth, cost and handling.
F.4.3	State what is meant by a geostationary satellite.	1	
F.4.4	State the order of magnitude of the frequencies used for communication with geostationary satellites, and explain why the up-link frequency and the down-link frequency are different.	3	
F.4.5	Discuss the relative advantages and disadvantages of the use of geostationary and of polar-orbiting satellites for communication.	3	Discussion should include the tracking of satellites, orbital heights and coverage.
F.4.6	Discuss the moral, ethical, economic and environmental issues arising from satellite communication.	3	

F5Electronics

5 hours

	Assessment statement	Obj	Teacher's notes
F.5.1	State the properties of an ideal operational amplifier (op-amp).	1	
F.5.2	Draw circuit diagrams for both inverting and non-inverting amplifiers (with a single input) incorporating operational amplifiers.	1	
F.5.3	Derive an expression for the gain of an inverting amplifier and for a non-inverting amplifier.	3	Students should be aware of the virtual earth approximation.
F.5.4	Describe the use of an operational amplifier circuit as a comparator.	2	Students will be expected to draw appropriate circuits. Output devices for comparator circuits may include light-emitting diodes (LEDs) and buzzers.
F.5.5	Describe the use of a Schmitt trigger for the reshaping of digital pulses.	2	
F.5.6	Solve problems involving circuits incorporating operational amplifiers.	3	

F6The mobile phone system

2 hours

	Assessment statement	Obj	Teacher's notes
F.6.1	State that any area is divided into a number of cells (each with its own base station) to which is allocated a range of frequencies.	1	Students should know that frequencies are allocated so as to avoid overlap between cells.
F.6.2	Describe the role of the cellular exchange and the public switched telephone network (PSTN) in communications using mobile phones.	2	The role of the cellular exchange in the selection and monitoring of base stations and the allocation of channels should be understood.
F.6.3	Discuss the use of mobile phones in multimedia communication.	3	
F.6.4	Discuss the moral, ethical, economic, environmental and international issues arising from the use of mobile phones.		

Option G: Electromagnetic waves (15/22 hours)

SL students study the core of these options and HL students study the whole option (the core and the extension material).

Aim 7: There are many computer simulations of interference, diffraction and other wave phenomena.

TOK: This is a good opportunity to show how the unifying concept of waves leads to a powerful synthesis.

Core material: G1–G4 are core material for SL and HL (15 hours).

Extension material: G5–G6 are extension material for HL only (7 hours).

G1The nature of EM waves and light sources

4 hours

	Assessment statement	Obj	Teacher's notes
Nature and properties of EM waves			
G.1.1	Outline the nature of electromagnetic (EM) waves.	2	Students should know that an oscillating electric charge produces varying electric and magnetic fields. Students should know that electromagnetic waves are transverse waves and all have the same speed in a vacuum. **Aim 8 and TOK:** Students could consider the possible health hazards associated with transmission lines.
G.1.2	Describe the different regions of the electromagnetic spectrum.	2	Students should know the order of magnitude of the frequencies and wavelengths of different regions, and should also be able to identify a source for each region.
G.1.3	Describe what is meant by the dispersion of EM waves.	2	
G.1.4	Describe the dispersion of EM waves in terms of the dependence of refractive index on wavelength.	2	No quantitative discussion is required.
G.1.5	Distinguish between transmission, absorption and scattering of radiation.	2	
G.1.6	Discuss examples of the transmission, absorption and scattering of EM radiation.	2	Students should study the effect of the Earth's atmosphere on incident EM radiation. This will lead to simple explanations for the blue colour of the sky, red sunsets or sunrises, the effect of the ozone layers, and the effect of increased CO_2 in the atmosphere. This links with 8.5.6.
Lasers			
G.1.7	Explain the terms monochromatic and coherent.	3	
G.1.8	Identify laser light as a source of coherent light.	2	
G.1.9	Outline the mechanism for the production of laser light.	2	Students should be familiar with the term population inversion.
G.1.10	Outline an application of the use of a laser.	2	Students should appreciate that lasers have many different applications. These may include: • medical applications • communications • technology (bar-code scanners, laser disks) • industry (surveying, welding and machining metals, drilling tiny holes in metals) • production of CDs • reading and writing CDs, DVDs, etc.

G2Optical instruments

6 hours

	Assessment statement	Obj	Teacher's notes
G.2.1	Define the terms *principal axis*, *focal point*, *focal length* and *linear magnification* as applied to a converging (convex) lens.	1	
G.2.2	Define the *power* of a *convex lens* and the *dioptre*.	1	
G.2.3	Define *linear magnification*.	1	
G.2.4	Construct ray diagrams to locate the image formed by a convex lens.	3	Students should appreciate that all rays incident on the lens from the object will be focused, and that the image will be formed even if part of the lens is

			covered.
G.2.5	Distinguish between a real image and a virtual image.	2	
G.2.6	Apply the convention "real is positive, virtual is negative" to the thin lens formula.	2	
G.2.7	Solve problems for a single convex lens using the thin lens formula.	3	
The simple magnifying glass			
G.2.8	Define the terms *far point* and *near point* for the unaided eye.	1	For the normal eye, the far point may be assumed to be at infinity and the near point is conventionally taken as being a point 25 cm from the eye.
G.2.9	Define *angular magnification*.	1	
G.2.10	Derive an expression for the angular magnification of a simple magnifying glass for an image formed at the near point and at infinity.	3	
The compound microscope and astronomical telescope			
G.2.11	Construct a ray diagram for a compound microscope with final image formed close to the near point of the eye (normal adjustment).	3	Students should be familiar with the terms objective lens and eyepiece lens.
G.2.12	Construct a ray diagram for an astronomical telescope with the final image at infinity (normal adjustment).	3	
G.2.13	State the equation relating angular magnification to the focal lengths of the lenses in an astronomical telescope in normal adjustment.	1	
G.2.14	Solve problems involving the compound microscope and the astronomical telescope.	3	Problems can be solved either by scale ray diagrams or by calculation.
Aberrations			
G.2.15	Explain the meaning of spherical aberration and of chromatic aberration as produced by a single lens.	3	
G.2.16	Describe how spherical aberration in a lens may be reduced.	2	
G.2.17	Describe how chromatic aberration in a lens may be reduced.	2	

G3Two-source interference of waves

3 hours

	Assessment statement	Obj	Teacher's notes
G.3.1	State the conditions necessary to observe interference between two sources.	1	
G.3.2	Explain, by means of the principle of superposition, the interference pattern produced by waves from two coherent point sources.	3	The effect may be illustrated using water waves and sound waves in addition to EM waves.
G.3.3	Outline a double-slit experiment for light and draw the intensity distribution of the observed fringe pattern.	2	This should be restricted to the situation where the slit width is small compared to the slit separation so that diffraction effects of a single slit on the pattern are not considered.
G.3.4	Solve problems involving two-source interference.	3	

G4 Diffraction grating

2 hours

	Assessment statement	Obj	Teacher's notes
Multiple-slit diffraction			
G.4.1	Describe the effect on the double-slit intensity distribution of increasing the number of slits.	2	
G.4.2	Derive the diffraction grating formula for normal incidence.	3	
G.4.3	Outline the use of a diffraction grating to measure wavelengths.	2	Use of the spectrometer is not included.
G.4.4	Solve problems involving a diffraction grating.	3	

G5 X-rays

4 hours

	Assessment statement	Obj	Teacher's notes
G.5.1	Outline the experimental arrangement for the production of X-rays.	2	A Coolidge tube is sufficient. Students should understand how the intensity and hardness of the X-ray beam are controlled.
G.5.2	Draw and annotate a typical X-ray spectrum.	2	Students should be able to identify the continuous and characteristic features of the spectrum and the minimum wavelength limit.
G.5.3	Explain the origins of the features of a characteristic X-ray spectrum.	3	
G.5.4	Solve problems involving accelerating potential difference and minimum wavelength.	3	
X-ray diffraction			
G.5.5	Explain how X-ray diffraction arises from the scattering of X-rays in a crystal.	3	This may be illustrated using 3 cm equipment.
G.5.6	Derive the Bragg scattering equation.	3	
G.5.7	Outline how cubic crystals may be used to measure the wavelength of X-rays.	2	Students should be aware of the fact that the structure of DNA was discovered by means of X-ray diffraction.
G.5.8	Outline how X-rays may be used to determine the structure of crystals.	2	
G.5.9	Solve problems involving the Bragg equation.	3	

G6Thin-film interference

3 hours

Aim 7: Computer simulations are useful here.

Aim 8: Some uses of thin films raise environmental and ethical issues (see G.6.10 and G.6.11).

	Assessment statement	Obj	Teacher's notes
Wedge films			
G.6.1	Explain the production of interference fringes by a thin air wedge.	3	Students should be familiar with the terms equal inclination and equal thickness.
G.6.2	Explain how wedge fringes can be used to measure very small separations.	3	Applications include measurement of the thickness of the tear film on the eye and oil slicks.
G.6.3	Describe how thin-film interference is used to test optical flats.	2	
G.6.4	Solve problems involving wedge films.	3	
Parallel films			
G.6.5	State the condition for light to undergo either a phase change of π, or no phase change, on reflection from an interface.	1	

G.6.6	Describe how a source of light gives rise to an interference pattern when the light is reflected at both surfaces of a parallel film.	2	
G.6.7	State the conditions for constructive and destructive interference.	1	
G.6.8	Explain the formation of coloured fringes when white light is reflected from thin films, such as oil and soap films.	3	
G.6.9	Describe the difference between fringes formed by a parallel film and a wedge film.	2	
G.6.10	Describe applications of parallel thin films.	2	Applications should include: • design of non-reflecting radar coatings for military aircraft • measurement of thickness of oil slicks caused by spillage • design of non-reflecting surfaces for lenses (blooming), solar panels and solar cells.
G.6.11	Solve problems involving parallel films.	3	These will include problems involving the application of thin films.

HL Options

Option H: Relativity (22 hours)

These options are available at HL only.

TOK: This is an opportunity to introduce the concept of a paradigm shift in relation to scientific understanding. The role of theories and their testing by experiment is crucial here. The meaning of time, the concepts of time dilation and length contraction, the absolute value of the velocity of EM waves are all stimulating ideas for discussion.

H1Introduction to relativity

1 hour

	Assessment statement	Obj	Teacher's notes
Frames of reference			
H.1.1	Describe what is meant by a frame of reference.	2	A *coordinate system* or set of axes within which to measure the position, orientation, and other properties of objects in it. It may refer to an *observational reference frame* tied to the state of motion of an observer. It may also refer to both an observational reference frame and an attached coordinate system as a unit.
H.1.2	Describe what is meant by a Galilean transformation.	2	In essence, the Galilean transformations embody the intuitive notion of addition and subtraction of velocity vectors. The assumption that time can be treated as absolute is at the heart of the Galilean transformations.
H.1.3	Solve problems involving relative velocities using the Galilean transformation equations.	3	

H2 Concepts and postulates of special relativity

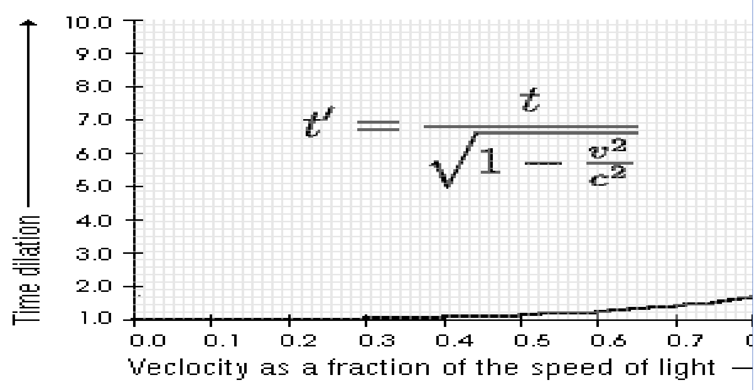
2 hours

	Assessment statement	Obj	Teacher's notes
H.2.1	Describe what is meant by an inertial frame of	2	Frame of reference with no acceleration.

	reference.		
H.2.2	State the two postulates of the special theory of relativity. Simply put: 1) There is no physical difference between two systems if the motion the systems are in is constant. 2) Speed of light is constant and independent of the motion of the emitting body.	1	1) The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems in uniform translatory motion relative to each other. 2) Light is always propagated in empty space with a definite velocity [speed] c which is independent of the state of motion of the emitting body.
H.2.3	Discuss the concept of simultaneity.	3	Students should know that two events occurring at different points in space and which are simultaneous for one observer cannot be simultaneous for another observer in a different frame of reference.

H3 Relativistic kinematics

5 hours

	Assessment statement	Obj	Teacher's notes
Time dilation			
H.3.1	Describe the concept of a light clock.	2	Only a very simple description is required here. For example, a beam of light reflected between two parallel mirrors may be used to measure time.
H.3.2	Define *proper time interval*.	1	Time taken as measured by an observer within their frame of reference
H.3.3	Derive the time dilation formula. http://www.drphysics.com/syllabus/time/time.html (length contraction derivation not needed)	3	Students should be able to construct a simple derivation of the time dilation formula based on the concept of the light clock and the postulates of relativity.
H.3.4	Sketch and annotate a graph showing the variation with relative velocity of the Lorentz factor.	3	
H.3.5	Solve problems involving time dilation.	3	
Length contraction			
H.3.6	Define *proper length*.	1	Length as measured by an observer within their frame of reference
H.3.7	Describe the phenomenon of length contraction.	2	The derivation of the length contraction formula is not required.
H.3.8	Solve problems involving length contraction.	3	

H4Some consequences of special relativity

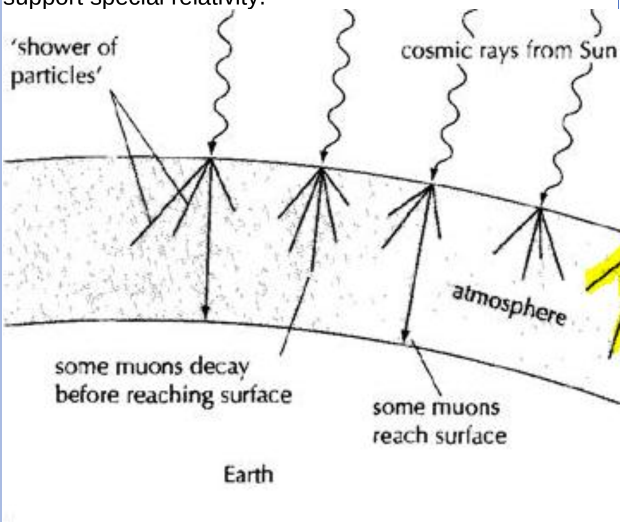
4 hours

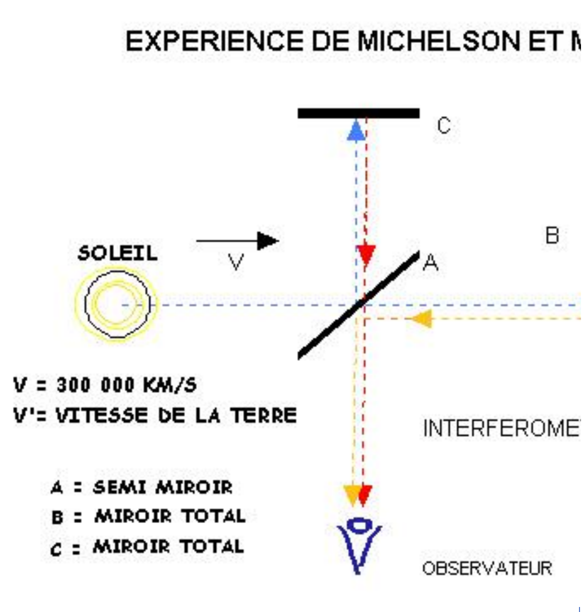
	Assessment statement	Obj	Teacher's notes
The twin paradox			
H.4.1	Describe how the concept of time dilation leads to the "twin paradox".	2	Different observers' versions of the time taken for a journey at speeds close to the speed of light may be compared. Students should be aware that, since one of the twins makes an outward and return journey, this is no longer a symmetrical situation for the twins.
H.4.2	Discuss the Hafele–Keating experiment.	3	Full understanding of this requires also General relativity. "During October, 1971, four cesium atomic beam clocks were flown on regularly scheduled commercial jet flights around the world twice, once eastward and once westward, to test Einstein's theory of relativity with macroscopic clocks. From the actual flight paths of each trip, the theory predicted that the flying clocks, compared with reference clocks at the U.S. Naval Observatory, should have lost 40+/-23 nanoseconds during the eastward trip and should have gained 275+/-21 nanoseconds during the westward trip ... Relative to the atomic time scale of the U.S. Naval Observatory, the flying clocks lost 59+/-10 nanoseconds during the eastward trip and gained 273+/-7 nanosecond during the westward trip, where the errors are the corresponding standard deviations. These results provide an unambiguous empirical resolution of the famous clock "paradox" with macroscopic clocks." J.C. Hafele and R. E. Keating, Science 177, 166 (1972)
Velocity addition			
H.4.3	Solve one-dimensional problems involving the relativistic addition of velocities.	3	The derivation of the velocity addition formula is not required.

Mass and energy			
H.4.4	State the formula representing the equivalence of mass and energy.	1	
H.4.5	Define *rest mass*.	1	Students should be aware that rest mass is an invariant quantity. Students should be familiar with the unit MeV c^{-2} for mass.
H.4.6	Distinguish between the energy of a body at rest and its total energy when moving.	2	
H.4.7	Explain why no object can ever attain the speed of light in a vacuum.	3	
H.4.8	Determine the total energy of an accelerated particle.	3	Students should be able, for example, to calculate the total energy of an electron after acceleration through a known potential difference.

H5Evidence to support special relativity

3 hours

	Assessment statement	Obj	Teacher's notes
H.5.1	Discuss muon decay as experimental evidence to support special relativity.  	3	Evidence: The evidence to support the Muon experiment is that theoretically, Muon particles should be undetected at the surface of the earth because it has such a short life time.'2.2 x 10^-6 seconds' as measured in actual time. In actuality Muon particles are detected on the Earth's surface, and therefore provides evidence to support special relativity. Conclusion: For the Muon's frame of reference the muon is experiencing proper time, but the length of the atmosphere is contracted to compensate for its speed. For the observer on earths frame of reference the muon is is travelling at the proper length, but has an dilated life time.
H.5.2	Solve problems involving the muon decay experiment.	3	
H.5.3	Outline the Michelson–Morley experiment. **Michelson and Morley** designed an **interferometer** which splits a light ray into two parts that follow different paths at right angles, are reflected by mirrors, and then recombine. If the rays have traveled slightly different distances, interference may occur when they recombine. If there is an 'aether wind' caused by motion of the rotating earth through the aether, this should affect the split rays differently. In addition, the apparatus could be rotated so that the light would be traveling in different directions, and the different combinations of aether wind and light wave directions would produce a changing interference pattern.	2	Students should be able to outline the principles of the Michelson interferometer using a simple sketch of the apparatus.

			
H.5.4	Discuss the result of the Michelson–Morley experiment and its implication. *Since then the Michelson-Morley Experiment has been repeated many times. In principle it is very simple, and consists in comparing the velocity of light in different directions. If the earth is moving through a stationary ether, it can be shown that two rays of light, the one moving in the direction of the earth's motion, and the other at right angles to it, should take unequal times to cover the same distance. But although the experiment has often been repeated, no difference has ever been found, although in some of these experiments the apparatus has been so delicate that a difference one hundred times less than the difference expected could have been measured.*	3	The implication that the ether does not exist and that the result is consistent with the constancy of the speed of light is the accepted explanation. In the end, the M&M experiment failed, no matter which orientation or location they performed the experiment in the speed of light always remain consistent. Therefore the scientist disproved the existence of "Aether" as well as provide the evidence to support the first postulate of relativity. "The constancy of the speed of light"
H.5.5	Outline an experiment that indicates that the speed of light in vacuum is independent of its source. a 1964 experiment at CERN used particles as the source of light. Neutral pions were produced by the collisions of 20 GeV protons on stationary nucleons in the proton synchrotron. With energies larger than 6 GeV, the pions had v/c ≥0.99975. Photons produced by the decay pion → gamma1 + gamma2 were collimated and timed over a 30 meter long light path. Because the protons in the synchrotron were pulsed, the speed of the photons could be measured by measuring the arrival times of their pulses as a function of the varying location of the detector along the light path. The result for the speed was 2.9977 ±0.0004 ×10^8 m/sec	2	Students should be familiar with pion decay experiments involving the decay of a fast-moving pion into two gamma ray (γ-ray) photons. The Pion Decay Experiment: The experiment analysed the decay of a particle called the Neutral Pion into two gamma-ray photons. The speed of the Neutral Pion was known to be travelling at 99.9% the speed of light, therefore the speed of the two gamma ray photons that are ejected from the neutral Pion must be even faster than that. In the end the speed of the Photons were measured to be consistent with the speed of light.

H6Relativistic momentum and energy

2 hours

Derivation of the relativistic momentum and energy formulae will not be examined.

	Assessment statement	Obj	Teacher’s notes
H.6.1	Apply the relation for the relativistic momentum of particles.	2	Students should be familiar with momentum expressed in the unit MeV c^{-1}.
H.6.2	Apply the formula for the kinetic energy of a particle.	2	
H.6.3	Solve problems involving relativistic momentum and energy.	3	Students should be able to calculate, for example, the kinetic energy, total energy, speed and momentum of an accelerated particle and for particles produced in reactions.

H7General relativity

4 hours

This section is intended as an introduction to the concepts of general relativity and is non-mathematical in its approach.

	Assessment statement	Obj	Teacher’s notes
The equivalence principle			
H.7.1	Explain the difference between the terms gravitational mass and inertial mass.	3	
H.7.2	Describe and discuss Einstein’s principle of equivalence.	3	Students should be familiar with Einstein’s closed elevator “thought experiment”. http://www.physics.fsu.edu/courses/spring98/ast3033/Relativity/GeneralRelativity.htm
H.7.3	Deduce that the principle of equivalence predicts bending of light rays in a gravitational field.	3	If light travels in a straight line it will appear to bend if you are in an accelerating frame of reference and the light is travelling perpendicular to your acceleration. If a frame of reference in a gravitational field is equivalent to an accelerating frame of reference then…. General relativity predicts that the path of light is bent in a gravitational field; light passing a massive body is deflected towards that body. This effect has been confirmed by observing the light of stars or distant quasars being deflected as it passes the Sun and by observing background stars during a Solar eclipse.
H.7.4	Deduce that the principle of equivalence predicts that time slows down near a massive body.	3	
Spacetime			
H.7.5	Describe the concept of spacetime.	2	The three dimentions of space plus the dimension of time make up space-time.
H.7.6	State that moving objects follow the shortest path between two points in spacetime.	1	

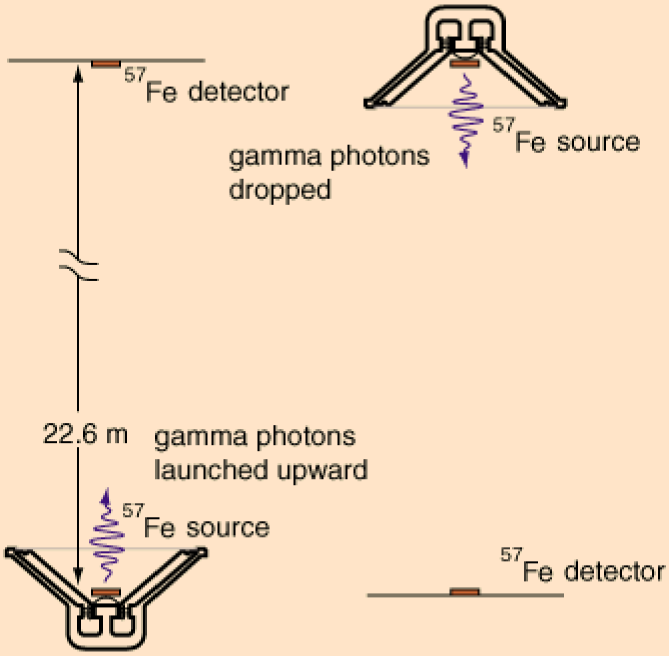
H.7.7	Explain gravitational attraction in terms of the warping of spacetime by matter.	3	Gravity can be reinterpreted, not as a force pulling on objects, but as a curvature of spacetime. Objects falling in a gravitational field—like around the Earth—aren't being pulled, but are simply moving along geodesics in the warped spacetime surrounding any heavy object. The Moon's orbit doesn't circle the Earth because of a pull, but because the straightest line through spacetime brings it back to the same point in space.
Black holes			
H.7.8	Describe black holes.	2	Students should know that black holes are a region of spacetime with extreme curvatures due to the presence of a mass.
H.7.9	Define the term *Schwarzschild radius*.	1	
H.7.10	Calculate the Schwarzschild radius.	2	
H.7.11	Solve problems involving time dilation close to a black hole.	3	
Gravitational red-shift			
H.7.12	Describe the concept of gravitational red-shift.	2	Students should be aware that gravitational red-shift is a prediction of the general theory of relativity. http://www.alcyone.com/max/writing/essays/gravitational-redshift.html
H.7.13	Solve problems involving frequency shifts between different points in a uniform gravitational field.	3	
H.7.14	Solve problems using the gravitational time dilation formula.	3	

H8Evidence to support general relativity

1 hour

	Assessment statement	Obj	Teacher's notes
H.8.1	Outline an experiment for the bending of EM waves by a massive object.	2	An outline of the principles used in, for example, Eddington's measurements during the 1919 eclipse of the Sun is sufficient. **Aim 8:** The ethical behaviour of Eddington and the limitations of data can be addressed here.
H.8.2	Describe gravitational lensing.	2	
H.8.3	Outline an experiment that provides evidence for gravitational red-shift. **Pound-Rebka Harvard Tower Experiment**	2	The Pound–Rebka experiment (or a suitable alternative, such as the shift in frequency of an atomic clock) and the Shapiro time delay experiments are sufficient. **Light travel time delay**

In just 22.6 meters, the fractional gravitational red shift is just 4.92×10^{-15} , but the Mossbauer effect with the 14.4 keV gamma ray fromiron-57 has a high enough resolution to detect that difference. In the early 60's physicists Pound, Rebka,and Snyder at the Jefferson Physical Laboratory at Harvard measured the shift to within 1% of the predicted shift.



By just using the expression for gravitational potential energy near the Earth, and using the m in the relativistic energy expression, the gain in energy for a photon which falls distance h is

$$\Delta E = mgh = \frac{E}{c^2} gh = \frac{14.4 keV}{c^2} g \cdot 22.6 m$$

$$\Delta E = 3.5x10^{-11} eV$$

Comparing the energy shifts on the upward and downward paths gives a predicted difference

$$\left(\frac{\Delta E}{E}\right)_{down} - \left(\frac{\Delta E}{E}\right)_{up} = \frac{2(3.5x10^{-11} eV)}{(14.4 keV)} = 4.9x10^{-15}$$

The measured difference was

testing (Shapiro)

Irwin I. Shapiro proposed another test, beyond the classical tests, which could be performed within the solar system. It is sometimes called the fourth "classical" test of general relativity. He predicted a relativistic time delay (Shapiro delay) in the round-trip travel time for radar signals reflecting off other planets.[30] The mere curvature of the path of a photon passing near the Sun is too small to have an observable delaying effect (when the round-trip time is compared to the time taken if the photon had followed a straight path), but general relativity predicts a time delay which becomes progressively larger when the photon passes nearer to the Sun due to the time dilation in the gravitational potential of the sun. Observing radar reflections from Mercury and Venus just before and after it will be eclipsed by the Sun gives agreement with general relativity theory at the 5% level.[31] More recently, the Cassini probe has undertaken a similar experiment which gave agreement with general relativity at the 0.002% level.[32] Very Long Baseline Interferometry has measured velocity-dependent (gravitomagnetic) corrections to the Shapiro time delay in the field of moving Jupiter [33][34] and Saturn.[35]

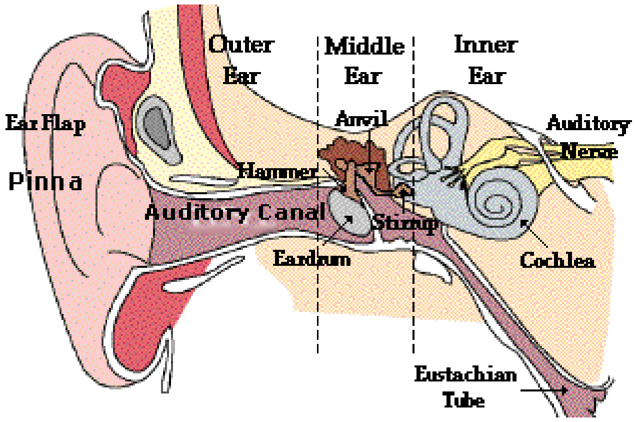
	$\left(\frac{\Delta E}{E}\right)_{down} - \left(\frac{\Delta E}{E}\right)_{up} = (5.1 \pm 0.5)x10^{-15}$ The success of this experiment owed much to the care of Pound and Rebka in preparing the source. They electroplated cobalt-57 onto the surface of a thin sheet of iron and then heated the combination at 1220 K for an hour. The heat treatment caused the cobalt to diffuse into the iron to a depth of about 300 nm or 1000 atomic spacings. The source was then mounted on the cone of a loudspeaker driven at 10Hz to sweep the source velocity in a sinusoidal variation. The detector was a thin sheet of iron about 14 micrometers thick which was also annealed. The heat treatments were found to be crucial in obtaining high resolution.		

Option I: Medical physics (22 hours)

These options are available at HL only.

I1 The ear and hearing

6 hours

	Assessment statement	Obj	Teacher's notes
I.1.1	Describe the basic structure of the human ear. 	2	The structure should be limited to those features affecting the physical operation of the ear.
I.1.2	State and explain how sound pressure variations in air are changed into larger pressure variations in the cochlear fluid. Overcoming the problem of getting airborne sound into the fluid-filled inner ear is solved by two main mechanisms: the concentration of energy from the large eardrum onto the small stirrup footplate situated in the oval window; and the lever-like action between the hammer and the anvil-stirrup complex. In cats, for example, the simple concentration of forces from the eardrum to the stirrup increases pressure at the oval window to about 35 times what is measured at the eardrum. The lever action of the middle ear bones	3	This can be dealt with in terms of the different areas of the eardrum and oval window, together with the lever action of the ossicles. Although the concept of impedance matching is not formally required, students should appreciate that, without a mechanism for pressure transformation between media of different densities (air and fluid), most sound would be reflected, rather than transmitted into the cochlear fluid.

	imparts a further mechanical advantage to the system—occurring because the anvil is shorter than the hammer—and further increases pressure by roughly 35 percent. In this way we overcome the problem of getting airborne vibrations into the pressurized, fluid-filled inner ear.		
I.1.3	State the range of audible frequencies experienced by a person with normal hearing.	1	
I.1.4	State and explain that a change in observed loudness is the response of the ear to a change in intensity.	3	Sound levels and hearing presentation
I.1.5	State and explain that there is a logarithmic response of the ear to intensity. Logarithmic response means that the perception of certain amount of sound increase is actually equivalent to an increase in intensity by a certain factor. i.e. We will hear two increases of 10dB as a linear increase whereas in fact a 10dB increase is approximately a three-fold increase in sound intensity. (actually 20dB is a ten-fold increase).  	3	
I.1.6	Define *intensity* and also *intensity level* (*IL*). $L_p = 10\log_{10}\left(\frac{{p_{rms}}^2}{{p_{ref}}^2}\right) = 20\log_{10}\left(\frac{p_{rms}}{p_{ref}}\right)$ dB	1	Intensity In a sound wave, the complementary variable to sound pressure is the acoustic particle velocity. Together they determine the acoustic intensity of the wave. The local instantaneous sound intensity is the product of the sound pressure and the acoustic particle velocity
I.1.7	State the approximate magnitude of the intensity level at which discomfort is experienced by a person with normal hearing.	1	Upwards of 70dB
I.1.8	Solve problems involving intensity levels.	3	**Aim 7, aim 8:** Data logging may be used to investigate traffic noise, etc.
I.1.9	Describe the effects on hearing of short-term and long-term exposure to noise. **Noise-induced hearing loss (NIHL)** – this is hearing loss due to exposure to either a sudden, loud noise or exposure to loud noises for a period of time. A dangerous sound is anything that is 85 dB (sound pressure level – SPL) or higher. [http://www.dangerousdecibels.org/education/information-center/hearing-loss/]	2	Students should be aware of temporary and permanent deafness, tinnitus and selective frequency losses. They should show an appreciation of the social implications of hearing loss on an individual. **Aim 8:** Legislation and the moral responsibility of employers could be considered.
I.1.10	Analyse and give a simple interpretation of graphs where IL is plotted against the logarithm of frequency for normal and for defective hearing.	3	

I2 Medical imaging

10 hours

Students should be able to discuss the advantages and disadvantages of various imaging techniques for particular purposes.

Aim 7: Students may like to consult databases of images available from teaching hospitals.

	Assessment statement	Obj	Teacher's notes
X-rays – X-Ray detention and display techniques presentation			
I.2.1	Define the terms *attenuation coefficient* and *half-value thickness*.	1	Students may study these concepts in the context of a parallel beam of X-rays but should appreciate their wider application.
I.2.2	Derive the relation between attenuation coefficient and half-value thickness.	3	
I.2.3	Solve problems using the equation .	3	Students may use simulation exercises to study X-ray attenuation.
I.2.4	Describe X-ray detection, recording and display techniques.	2	Students should be aware of photographic film, enhancement, electronic detection and display.
I.2.5	Explain standard X-ray imaging techniques used in medicine.	3	Students should appreciate the causes of loss of sharpness and of contrast in X-ray imaging. They should be familiar with techniques for improving sharpness and contrast.
I.2.6	Outline the principles of computed tomography (CT). CAT scan presentation	2	Students should be able to describe how a three-dimensional image is constructed.
Ultrasound – Ultrasound presentation			
I.2.7	Describe the principles of the generation and the detection of ultrasound using piezoelectric crystals.	2	
I.2.8	Define *acoustic impedance* as the product of the density of a substance and the speed of sound in that substance.	1	
I.2.9	Solve problems involving acoustic impedance.	3	Students should understand the use of a gel on the surface of the skin.
I.2.10	Outline the differences between A-scans and B-scans.	2	
I.2.11	Identify factors that affect the choice of diagnostic frequency.	2	Students should appreciate that attenuation and resolution are dependent on frequency.
NMR and lasers			
I.2.12	Outline the basic principles of nuclear magnetic resonance (NMR) imaging. NMR Presentation	2	Students need only give a simple qualitative description of the principle, including the use of a non-uniform magnetic field in conjunction with the large uniform field.
I.2.13	Describe examples of the use of lasers in clinical diagnosis and therapy.	2	Applications such as the use in pulse oximetry and in endoscopes should be discussed. Students should be familiar with the use of a laser as a scalpel and as a coagulator.

I3 Radiation in medicine

6 hours

Aim 8: Moral, ethical and social implications of the use of radiation should be discussed where appropriate.

	Assessment statement	Obj	Teacher's notes
I.3.1	State the meanings of the terms exposure, absorbed dose, quality factor (relative biological effectiveness) and dose equivalent as used in radiation dosimetry.	1	Students should be able to discuss the significance of these quantities in radiation dosimetry.

I.3.2	Discuss the precautions taken in situations involving different types of radiation.	3	Students should consider shielding, distance and time-of-exposure factors. They should be familiar with the film badge. **TOK:** They should appreciate that current practice is determined from a gradual increase in available data.
I.3.3	Discuss the concept of balanced risk.	3	**Aim 8, Int, TOK:** Students should appreciate that codes of practice have been developed for conduct involving the use of radiations.
I.3.4	Distinguish between physical half-life, biological half-life and effective half-life.	2	Students should be able to calculate the effective half-life from the physical half-life and the biological half-life.
I.3.5	Solve problems involving radiation dosimetry.	3	
I.3.6	Outline the basis of radiation therapy for cancer.	2	This should include the differential effects on normal and malignant cells, as well as a description of the types of sources available.
I.3.7	Solve problems involving the choice of radio-isotope suitable for a particular diagnostic or therapeutic application.	3	Students should be familiar with a variety of techniques. Where reference is made to a specific technique, sufficient description will be given for the student to be able to answer any questions on that technique.
I.3.8	Solve problems involving particular diagnostic applications.	3	For example, assessment of total blood volume. Where reference is made to a specific technique, sufficient description will be given for the student to be able to answer any questions on that technique.

Option J: Particle physics (22 hours)

These options are available at HL only.

A free CD-Rom produced by CERN (also available on the CERN web site) covers all the material in this option.

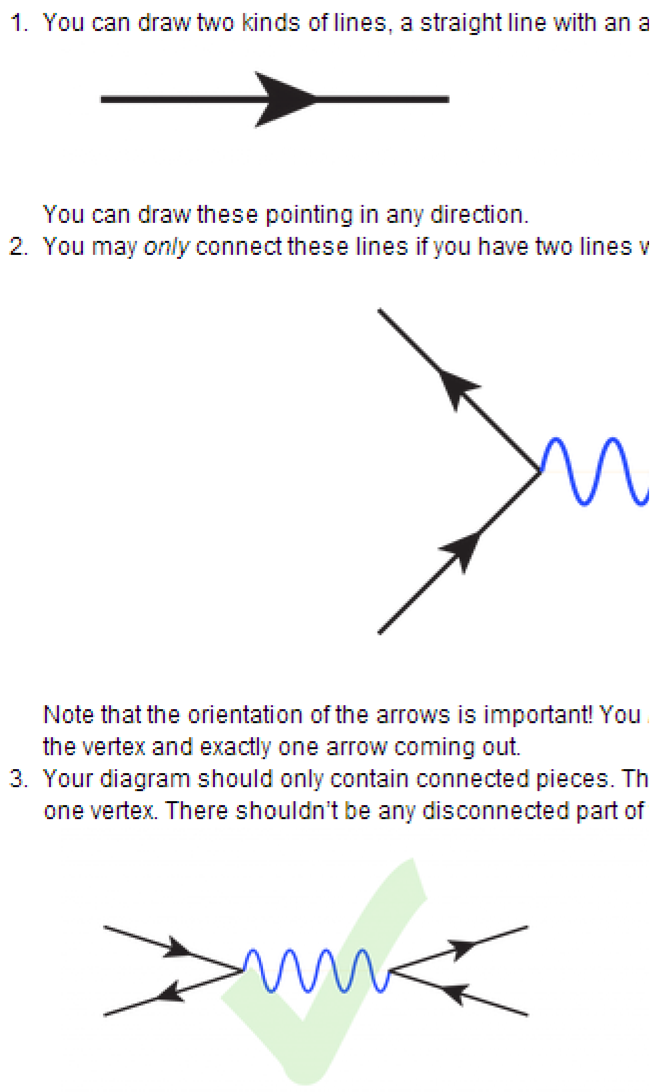
In this option, all masses are assumed to be rest masses.

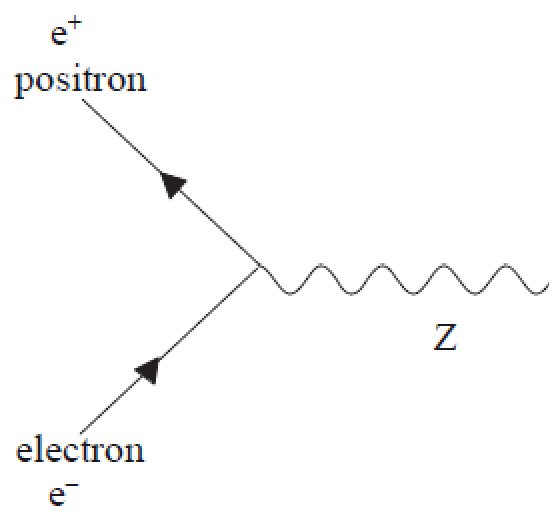
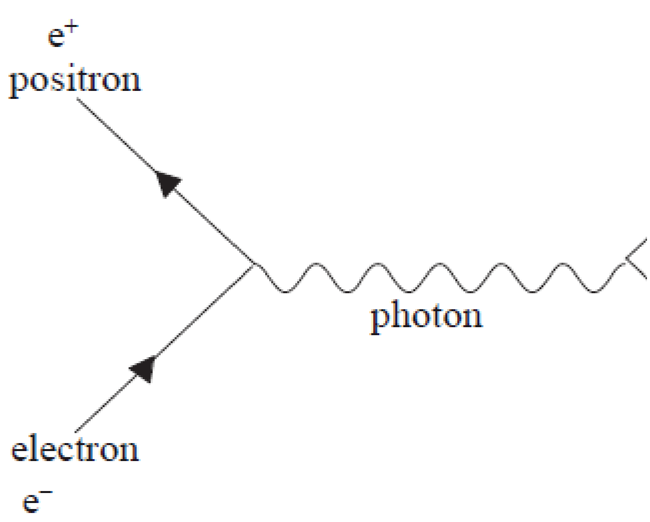
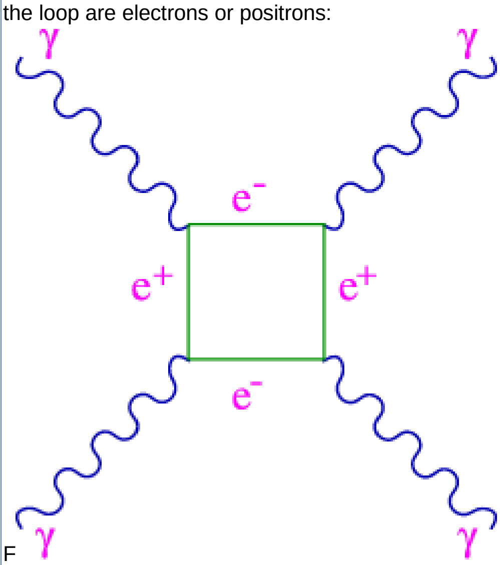
TOK: This whole option contains a wealth of information for discussion, for example, the nature of observation, the meaning of measurement, and the meaning of evidence. How developments in one field lead to breakthroughs in another is also a fascinating topic, for example, particle physics and cosmology.

J1 Particles and interactions

5 hours

	Assessment statement	Obj	Teacher's notes
Description and classification of particles			
J.1.1	State what is meant by an elementary particle.	1	Particles are called elementary if they have no internal structure, that is, they are not made out of smaller constituents.
J.1.2	Identify elementary particles.	2	The classes of elementary particles are quarks, leptons and exchange particles. The Higgs particle could be elementary.
J.1.3	Describe particles in terms of mass and various quantum numbers.	2	Students must be aware that particles (elementary as well as composite) are specified in terms of their mass and various quantum numbers. They should consider electric charge, spin, strangeness, colour, lepton number and baryon number.
J.1.4	Classify particles according to spin.	1	
J.1.5	State what is meant by an antiparticle.	1	
J.1.6	State the Pauli exclusion principle.	1	
Fundamental interactions			
J.1.7	List the fundamental interactions.	1	Since the early 1970s the electromagnetic and weak interactions have been shown to be two aspects of the same interaction, the electroweak interaction.

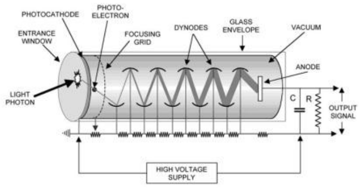
J.1.8	Describe the fundamental interactions in terms of exchange particles.	2	
J.1.9	Discuss the uncertainty principle for time and energy in the context of particle creation.	3	A simple discussion in terms of a particle being created with energy ΔE existing no longer than a time Δt given by .
Feynman diagrams - [Feynman diagram presentation]			
J.1.10	Describe what is meant by a Feynman diagram. The straight lines show particles. The wiggly lines show virtual particles. At each vertex (meeting point) matter particles are drawn with arrows showing their movement in time. Anti-matter particle arrows are reversed.	2	
J.1.11	Discuss how a Feynman diagram may be used to calculate probabilities for fundamental processes.	3	Numerical values of the interaction strengths do not need to be recalled.
J.1.12	Describe what is meant by virtual particles.	2	Virtual particles are particles that exist temporarily. They are exchange particles necessary for interactions to take place
J.1.13	Apply the formula for the range R for interactions involving the exchange of a particle.	2	Applications include Yukawa's prediction of the pion or determination of the masses of the $W^{\pm}$, Z^0 from knowledge of the range of the weak interaction.
J.1.14	Describe pair annihilation and pair production through Feynman diagrams.	2	Example

			
J.1.15	Predict particle processes using Feynman diagrams.	3	For example, the electromagnetic interaction leads to photon–photon scattering (that is, scattering of light by light). The particles in the loop are electrons or positrons:  F

J2 Particle accelerators and detectors

6 hours

	Assessment statement	Obj	Teacher’s notes
Particle accelerators – Accelerators presentation			
J.2.1	Explain the need for high energies in order to produce particles of large mass.	3	
J.2.2	Explain the need for high energies in order to resolve particles of small size.	3	Students should know that, to resolve a particle of size *d*, the de Broglie wavelength of the particle used to scatter from it must be of the same order of magnitude as *d*. The connection with diffraction may prove useful here.
J.2.3	Outline the structure and operation of a linear accelerator and of a cyclotron.	2	
J.2.4	Outline the structure and explain the operation of a synchrotron.	3	Students should be able to explain how the charged beams are accelerated, why the magnetic fields must vary and why the ring has a large radius.
J.2.5	State what is meant by bremsstrahlung (braking) radiation.	1	
J.2.6	Compare the advantages and	3	

	disadvantages of linear accelerators, cyclotrons and synchrotrons.		
J.2.7	Solve problems related to the production of particles in accelerators.	3	These include the total energy of the particle in terms of its mass and kinetic energy, and the total energy available from the collision of a particle with a stationary target.
Particle detectors			
J.2.8	Outline the structure and operation of the bubble chamber, the photomultiplier (diagram below)  and the wire chamber. http://en.wikipedia.org/wiki/Wire_chamber	2	Bubble chamber – first 5 minutes of http://www.youtube.com/watch?v=qcUwLH8L5AU The great advantage of photomultipliers is their extreme sensitivity. They are able to multiply the signal produced by the incident light by figures up to 100 million. In addition to their very high levels of gain, photomultipliers also exhibit a low noise level, high frequency response and a large collection area. These advantages have meant that despite all the advances in photodiode technology, photomultipliers are still used in virtually all cases when low levels of light need to be detected.
J.2.9	Outline international aspects of research into high-energy particle physics.	2	Students should be aware that governments need to collaborate to construct and operate large-scale research facilities. There are very few accelerator facilities, for example, CERN, DESY, SLAC, Fermilab and Brookhaven. Results are disseminated and shared by scientists in many countries.
J.2.10	Discuss the economic and ethical implications of high-energy particle physics research.	3	Students should be aware that, even at the height of the Cold War, Western and Soviet scientists collaborated in the field of particle physics.

J3 Quarks – Quarks presentation

2 hours

	Assessment statement	Obj	Teacher's notes
J.3.1	List the six types of quark.	1	Up, Down, Strange, Charm, Top, Bottom
J.3.2	State the content, in terms of quarks and antiquarks, of hadrons (that is, baryons and mesons). Mesons are part of the hadron particle family, defined simply as particles composed of quarks. The other members of the hadron family are the baryons: subatomic particles composed of three quarks rather than two. Since quarks have a spin of 1/2, the difference in quark-number between mesons and baryons results in mesons being bosons while baryons are fermions—that is, mesons have integer spin while baryons have half-integer spin. This means that the Pauli exclusion principle applies to each type of baryon, but does not apply to mesons.	1	Baryons: 3 quarks of different colours Mesons: A pair of quarks one quark and one anti-quark
J.3.3	State the quark content of the proton and the neutron.	1	Proton: Up, Up, Down (up is positive!) Neutron: Up, Down, Down
J.3.4	Define baryon number and apply the law of conservation of baryon number.	2	Students should know that baryon number is conserved in all reactions.

J.3.5	Deduce the spin structure of hadrons (that is, baryons and mesons).	3	Only an elementary discussion in terms of spin "up" and spin "down" is required.
J.3.6	Explain the need for colour in forming bound states of quarks.	3	Students should realize that colour is necessary to satisfy the Pauli exclusion principle. The fact that hadrons have no colour is a consequence of confinement.
J.3.7	State the colour of quarks and gluons.	1	
J.3.8	Outline the concept of strangeness.	2	It is sufficient for students to know that the strangeness of a hadron is the number of anti-strange quarks minus the number of strange quarks it contains. Students must be aware that strangeness is conserved in strong and electromagnetic interactions, but not always in weak interactions.
J.3.9	Discuss quark confinement.	3	Students should know that isolated quarks and gluons (that is, particles with colour) cannot be observed. The strong (colour) interaction increases with separation. More hadrons are produced when sufficient energy is supplied to a hadron in order to isolate a quark.
J.3.10	Discuss the interaction that binds nucleons in terms of the colour force between quarks.	3	It is sufficient to know that the interaction between nucleons is the residual interaction between the quarks in the nucleons and that this is a short-range interaction.

J4 Leptons and the standard model

2 hours

	Assessment statement	Obj	Teacher's notes
J.4.1	State the three-family structure of quarks and leptons in the standard model.	1	Students should know that the standard model is the presently accepted theory describing the electromagnetic and weak interactions of quarks and leptons.
J.4.2	State the lepton number of the leptons in each family.	1	
J.4.3	Solve problems involving conservation laws in particle reactions.	3	Students should know that electric charge, total energy, momentum, baryon number and family lepton number are conserved in all particle reactions. Strangeness is conserved in strong and electromagnetic interactions, but not always in weak interactions.
J.4.4	Evaluate the significance of the Higgs particle (boson).	3	Students should know that particles acquire mass as a result of interactions involving the Higgs boson.

J5 Experimental evidence for the quark and standard models - Presentation

5 hours

	Assessment statement	Obj	Teacher's notes
J.5.1	State what is meant by deep inelastic scattering.	1	
J.5.2	Analyse the results of deep inelastic scattering experiments.	3	Students should appreciate that these experiments provide evidence for the existence of quarks, gluons and colour.
J.5.3	Describe what is meant by asymptotic freedom: "the strength of the strong interaction decreases as the energy available for the interaction increases."	2	This means that quarks are much less likely to interact as they get farther apart. The Strong forec has a short range.
J.5.4	Describe what is meant by neutral current. "processes involving Z^0 exchange" The unification of Electromagnetic and Weak nuclear forces into the Electro-weak interaction was possible according to the standard model if there was a	2	This theoretical boson was hard to detect because it was neutral so it did not interact with detectors. High energy collisions beteen protons and anti-protons produced sufficient Z^0 for detection of the positron-electron pair it decays into.

	massive neutral boson to mediate certain exchanges.		
J.5.5	Describe how the existence of a neutral current is evidence for the standard model.	2	Students should know that only the standard model predicts weak interaction processes involving the exchange of a massive, neutral particle (the Z^0 boson).

J6 Cosmology and strings

2 hours

	Assessment statement	Obj	Teacher's notes
J.6.1	State the order of magnitude of the temperature change of the universe since the Big Bang.	1	The temperature of the universe was 10^{32} K at 10^{-43} s after the Big Bang and is 2.7 K at present.
J.6.2	Solve problems involving particle interactions in the early universe ***Average kinetic energy of particles = 3/2 k T.*** ***Note that for a given temperature T this equations gives the average kinetic energy so there will be some particles at significantly higher enery levels than this. This formula can be used to obtain an order of magnitude for the Temperatures at which particles have enough kinetic energy for certain reactions to occur.***	3	For example, problems will include calculation of the temperature: • at which production of electron–positron pairs becomes possible the rest mass plus kinetic energy of colliding particles is breat enough to create the pair. • at which nucleosynthesis can take place the kinetic energy of a baryon is sufficient for it to get close enough to another baryon for nuclear force to act. • when the universe becomes transparent to radiation. As the universe expanded, however, it became cooler and less dense. About 300,000 years after the start of expansion, the temperature of the universe had cooled to 3000 Kelvin. At this temperature: • Protons and electrons combined to form neutral hydrogen atoms. (This process is known to physicists as **recombination**.) • The universe, lacking free electrons to scatter the photons, suddenly became transparent. • The liberated photons started streaming freely in all directions
	State that the early universe contained almost equal numbers of particles and antiparticles.	1	
J.6.4	Suggest a mechanism by which the predominance of matter over antimatter has occurred.	3	A simple explanation in terms of the impossibility of photons materializing into particle–antiparticle pairs once the temperature fell below a certain value is all that is required.
J.6.5	Describe qualitatively the theory of strings.	2	Students should be aware that the failure to reconcile gravitation with quantum theory has created the idea of a string as the fundamental building block of matter. The known fundamental particles are modes of vibration of the string similar to the harmonics of an ordinary vibrating string. http://www.ted.com/talks/brian_greene_on_string_theory.html