A Level Physics Online

OCR B Physics – H557

Module 5: Rise and Fall of the Clockwork Universe

You should be able to demonstrate and show your understanding of:	Progress and understanding:			
	1	2	3	4
5.1.3 Our Place in the Universe				
Distances and Measurements: -Lightyear: The distance light travels in a year (1ly = 9.5×10^{15}m) -Astronomical Unit: The average distance between the Earth and Sun (1AU = 1.5×10^{11}m) -Arcsecond (″): One 3600th of a degree -Arcminute: One 60th of a degree -Parsec: The distance away an object must be to have a parallax of one arcsecond when observed from Earth (1pc = 3.1×10^{16}m = 3.3ly)				
Hertzsprung – Russell Diagram: Shows how the luminosity and temperature of different stars compare. Luminosity on the y-axis, temperature on the x-axis. Both axes are log scales. The temperature scale runs backwards, hottest on the left and coolest on the right.				
Radar: Stands for 'Radio Detection and Ranging'. It makes use of radio waves to determine the distance to an object, hence speed and acceleration can be determined by calculation. It only works for short distances because the delay, Δt, becomes greater and the signal becomes weaker for larger distances				
Distance to and Velocity of an Asteroid: 1) Send out a pulse, pulse returns, record time for pulse to return, Δt_1 2) Wait a certain amount of time (e.g. 100 seconds) 3) Send a second pulse, pulse returns, record time for pulse to return, Δt_2 4) Find the distance the asteroid is at before and after the '100s' by multiplying each recorded time (from 1) and 3)) by the speed of light (speed of radio waves) 5) Find Δs, the distance travelled in the certain time (e.g. 100 seconds) 6) $Relative\ velocity, v = \frac{\Delta s}{certain\ time\ (e.g. 100\ seconds)}$				
Assumptions for Determining Asteroid Speed: -Speed of the signal is the same both ways (constant speed of light) -Moment of reflection is halfway through each time delay, Δt				

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Distance to the Moon: Lidar is used, ' Light detection and ranging'. Lasers are emitted from Earth and reflected off reflectors left by Apollo				
Parallax: When close stars seem to shift their position against a background of fixed stars. The parallax angle, p, is half the angle that the star appears to move through (in 6 months). From the trigonometry of the situation; $tanp = \frac{r}{d}$ so for small p $tanp \approx p$ hence $p = \frac{r}{d} \rightarrow d = \frac{r}{p}$ Where r is the distance between the Earth and Sun, and d is the distance from the Sun to the near star that is being observed. (So, when working in astronomical units, d=1/p) -The smaller d is (closer to Earth), the more parallax it shows as the Earth orbits the Sun				
Standard Candle: A star of known absolute luminosity that is used as a comparative measure for other stars				
Absolute Luminosity, L_O: The brightness a star would have at a 'standard' distance of 10 parsecs (This is a star's 'true' brightness) -A dim star with a high L_O is more distant than one with the same L_O with a higher apparent brightness				
Cepheid Variables: Stars that vary their brightness with a constant period. A greater L_O of a Cepheid variable means they vary with a longer period. They are used as standard candles; the variation of its brightness can be used to find its absolute luminosity.				
$Relative\ Luminosity = \frac{L}{L_\odot} = \frac{Luminosity}{Luminosity\ of\ the\ Sun}$				
Doppler Shift: A change in the observed wavelength due to the relative motion of the source and observer -Spectral lines of a star are caused by atoms absorbing/emitting light at a particular wavelength. Receding stars show red shift, approaching stars show blue shift.				
-For a relative velocity of zero between the source and observer, the source emits waves of wavelength, λ, separated by equal time intervals T, so λ = cT For a relative velocity of v, the source recedes and so the observed wavelength appears stretched. This is because between the emission of any two peaks, the source had travelled an extra distance vT away. So λ increases by Δλ = vT; $z = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ -This equation shows the fractional increase in λ, z. It is correct for velocities much less than the speed of light. For velocities near the speed of light special relativity modifies this (outside of course)				

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Cosmological Redshift: For large red shifts, we can interpret this as space expanding; the wavelength of light stretches along with the space through which it travels. This is the cosmological redshift. It can be shown that space stretches by a factor z+1 for a given doppler (red)shift; $$\frac{R_{observed}}{R_{emitted}} = \frac{\lambda_{observed}}{\lambda_{emitted}} = \frac{\lambda_{emitted} + \Delta\lambda}{\lambda_{emitted}} = 1 + \frac{\Delta\lambda}{\lambda} = 1 + z$$ Where R = distance between two galaxies				
Hubble's Law: Distant galaxies are moving away at a speed proportional to their distance $$v = H_O r$$ Where v = recession velocity, H_O = Hubble constant, r = distance. $\frac{1}{H_O} = \frac{r}{v}$ This is 'Hubble time', the time since galaxies were close together i.e. the time scale of the universe -A bigger H_O means the younger the universe is, so the faster it must have expanded to reach its present size				
Big Bang: The probable origin of the universe, a very hot, dense state from which it has expanded and cooled				
CMBR: Microwave radiation that permeates the universe, it is red shifted radiation from an early hot stage of the universe. It has the largest known redshift, it was produced with a wavelength of the order 1μm, now it is of the order 1mm, 1000x larger. The temperature has also fallen by a factor of a 1000, 3000K to 3K. -The CMBR shows variation in temperature, from these non-uniformities stars and galaxies are formed -The cosmological expansion has stayed the same however; $$z + 1 = \frac{r\ of\ universe\ now}{r\ of\ universe\ then}$$				
Special Relativity: Explains the motion of bodies with very high speeds, close to the speed of light. (Low speeds produce the results as predicted by Newton's Laws)				
First Postulate: The laws of physics are the same for all observers in all inertial reference frames of reference (see below). So physical behaviour cannot depend on any absolute velocity				
Second Postulate: The speed of light is the same for all inertial frames of reference. And does not depend on the motion of the light source or observer (In other words, the speed of light in free space is invariant)				
Inertial Frames of Reference: Nothing is truly 'at rest' or truly 'moving', only relative to another object. Inertial frames of reference are frames with a constant or zero velocity. i.e. where Newton's Laws apply, as there is no net external force acting on the frame				

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If a train travels at $60ms^{-1}$ and then a ball is thrown at $5ms^{-1}$ on the train; in the train's frame of reference the ball has a speed of $5ms^{-1}$. In the reference frame of an observer, outside the train, the ball has a speed of $65ms^{-1}$				
Space-Time/Minkowski Diagrams: The line that an object traces out on a space-time diagram is called a worldline. For an object moving at a non-zero relative velocity, its worldline moves up the time axis (y-axis) to or away from the observer (x=0). For an object with zero relative velocity, it traces a vertical worldline on the space-time diagram. -A light pulse travels at 1 light second per second so has a worldline at 45 degrees. Due to the second postulate this is true for every space-time diagram. A steeper gradient means the object is moving slower (moving less distance during a longer time). A worldline cannot have an angle of less than 45 degrees as objects cannot travel faster than the speed of light				
Assumptions for Space-Time Diagrams: Speed of light is constant, so the reflection occurs halfway through the 'flight time' of the pulse to and from the object. Also, we assume that the speed of light is not affected by the motion of the distant object				
Time Dilation and Light Clock Thought Experiment: The amount of time between two events differs depending on whether you are at rest relative to them. Clocks moving relative to an observer run slowly as seen by the observer - Light clock: A pair of mirrors between which light bounces. One tick is when the light travels to the other mirror and back. Consider a stationary light clock on a train where the light pulse bounces vertically, i.e. as viewed by a person on the train. The distance to the other mirror is $d = ct_o$, so the time to return to the same mirror is $2t_o$; t_o is the time as measured by a stopwatch on the train - The train moves with a speed, v, so an observer outside the train sees the train move a horizontal distance $x = vt$ in a time, t; t is the time as measured by a stopwatch in the frame of the observer. According to the observer, the light pulse moves at an angle a distance ct there and a distance ct back to the first mirror. $t > t_o$ so ct is greater than ct_o, hence the observer sees the clock 'tick' slower when the clock is moving. -Using a diagram this mathematical derivation can be seen to only need Pythagoras' Theorem; 1) $(ct)^2 = (ct_o)^2 + (vt)^2 \quad \rightarrow \quad (ct_o)^2 = (ct)^2 - (vt)^2$ 2) $t_o{}^2 = t^2 - \frac{v^2t^2}{c^2} \quad \rightarrow \quad t_o{}^2 = t^2\left(1 - \frac{v^2}{c^2}\right)$ 3) $t_o = t\sqrt{\left(1 - \frac{v^2}{c^2}\right)} \quad \rightarrow \quad t = \frac{t_o}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$ $t = \gamma t_o$ $'Dilated\ Time' = \gamma \times Proper\ Time$				

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Lorentz Factor (relativistic factor), γ: The factor by which time changes for an object while that object is in motion as measured by an observer. $$\gamma = \frac{1}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$ [Note: If v tends to 0, γ tends to 1, so $t = t_o$, same as predicted by Newton's Laws. Also, if v = c, then we get γ = 1/0 which is an undefinable quantity, so this supports the idea that nothing can go faster than the speed of light (superluminal travel is impossible)]				
Proper Time: Proper time, denoted t_o in the example above, is the time interval between two events that appear to occur at the same point. In our example these two events are the emitting and rebounding of a light pulse. Proper time can only be measured by an observer at rest with respect to the event happening (in our example, by an observer on the train; they see the light clock as stationary with the light bouncing vertically). In other words, proper time only needs one stopwatch to measure the time between events, as there is no relative velocity to consider. -So, in our example proper time is on the train.				
[Note: The mathematics involved in special relativity is not too difficult, only Pythagoras' Theorem and algebraic manipulation. The difficult part is understanding the concept, in particular the difference between proper time, measured in a stationary frame of reference wrt the events; and 'dilated' time, measured in a moving frame of reference wrt the events.] [Note: The first thing you should do in an exam question involving relativity is determine which reference frame views the event as stationary; from this you can say that the proper time is measured in that reference frame. From there it is a matter of ensuring the numbers you are given are plugged into the equation the correct way around]				