PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 10: SPACE

DOPPLER EFFECT, REDSHIFT AND HUBBLE'S LAW

SCORE	PERCENTAGE
/183	%

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Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • The fractional change in wavelength is proportional to the relative velocity of the source (1) • Hence the change in wavelength is proportional to the wavelength (1) **OR** • $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ and v and c are the same for all wavelengths **Or** $\frac{\Delta\lambda}{\lambda} = z$ and z is constant (1) • change in wavelength is proportional to the wavelength **Or** rearranges, e.g. $\Delta\lambda = x\lambda$ to demonstrate $\Delta\lambda$ is proportional to λ (1)		**2**

Q2.

Question Number	Answer		Mark
(a)	photon absorbed by electron	(1)	
	electron moves to higher energy level **Or** electron excited	(1)	
	where photon energy = difference in energy levels	(1)	
	only certain changes/differences possible	(1)	
	between discrete energy levels	(1)	5
(b)(i)	Use of $E = hf$	(1)	
	Use of conversion factor to eV	(1)	
	Energy of photon = 1.91 (eV)	(1)	
	Identify levels 3.41 (eV) and 1.51 (eV) **Or** levels 1 and 2	(1)	4
	Example of calculation		
	$E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz (= 3.05×10^{-19} J)		
	$E = 6.63 \times 10^{-34}$ J s $\times$ 4.6×10^{14} Hz $\div$ 1.6×10^{-19} J s		
	= 1.91 eV		
	= 3.41 eV − 1.51 eV (1.90 eV) as the closest match		
(b)(ii)	Just-free electrons have zero energy state		
	Or energy value of level $n = \infty$ is 0	(1)	
	(Bound) electrons need to gain energy to attain this state		
	Or electrons need to gain energy to move to a higher level	(1)	2
	(Accept Because they must gain energy to move up for second mark)		
	(accept answers in terms of ionisation energy)		
(c)	Look for corresponding pattern of lines / frequency spacings at different place in spectrum **Or** reference to known normal positions	(1)	
	moving away increases observed wavelength / decreases frequency (or the case for moving towards)	(1)	
	so if shifted to red end then moving away (or blue = towards) **Or** the greater the velocity the greater the change in frequency	(1)	3
	Total for question		**14**

Q3.

Question Number	Answer		Mark
(a)*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Electrons/atoms move to higher energy levels / get excited They then move to lower energy levels (accept ground state) The energy from the move is given out in the form of a <u>photon</u> The energy levels are discrete **Or** only certain energy levels are possible The energy of the photon must be equal to the difference in energy levels **Or** $hf = E_2 - E_1$ There are only a limited number of energy differences and only a corresponding number of frequencies (looking for differences /changes **not** levels) (The marks above may be obtained from a suitably labelled diagram – but the order of excitation and de-excitation cannot be assumed for two marks just from the presence of both)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**6**
(b)	Doppler (accept blue shift) The wavelength of the radiation is decreased / frequencies increases Star moving towards Earth or vice versa	**(1)** **(1)** **(1)**	**3**
(c)	Light behaves as both particle and wave **Or** wave-particle duality	**(1)**	**1**
	Total for question		**10**

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An answer that makes reference to the following: • because the helium atoms are moving, there is a change in frequency/ wavelength of the emitted light (1) • for particles moving away from the observer there will be an decrease in frequency and for particles moving towards the observer there will be an increase in frequency OR for particles moving away from the observer there will be an increase in wavelength and for particles moving towards the observer there will be an decrease in wavelength (1)		**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)(1)	• use of $v/c = \Delta\lambda/\lambda$ • $v = 1530\ \text{m s}^{-1}$	Example of calculation: $v / 3 \times 10^{8}\ \text{m s}^{-1} = 3 \times 10^{-3}\ \text{nm} / 587\ \text{nm}$ $v = 1530\ \text{m s}^{-1}$	**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)(2)	• mass of helium atom = 4u • use of $\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$ • $T = 375\ \text{K}$	Example of calculation: Mass of He atom = $4 \times 1.66 \times 10^{-27}\ \text{kg} = 6.64 \times 10^{-27}\ \text{kg}$ $\frac{1}{2}\ 6.64 \times 10^{-27}\ \text{kg} \times (1530\ \text{m s}^{-1})^2 = 3/2 \times 1.38 \times 10^{-23}\ \text{J K}^{-1} \times T$ $T = 375\ \text{K}$	**(3)**

Q5.

Question Number	Answer	Mark
	C	**1**

Q6.

Question Number	Answer	Mark
	D	**1**

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	• The frequency/wavelength (of a line in the spectrum) emitted by the star must be measured **(1)** • Determine the difference between this frequency/wavelength and that emitted in the lab **(1)** • (The Doppler equation is used to) determine the speed of the star (relative to the Earth) $v/c = \Delta f/f_0$ or $v/c = \Delta\lambda/\lambda_0$ **(1)** • Clear indication (stated in words or via a formula) that v is positive/approaching when the frequency has increased and negative/receding when it has decreased **Or** corresponding statement about wavelength **(1)**	MP2 – accept in terms of difference between measured frequency/wavelength with average frequency/wavelength	**4**

Q8.

Question Number	Answer	Mark
	A	1

Q9.

Question Number	Answer		Mark
(a)(i)	Redshift is the (fractional) increase in wavelength received (by an observer)	(1)	
	Due to source and observer receding (from each other)	(1)	2
6(a)(ii)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate**		
	Measure frequency/wavelength of light (from the galaxy)	(1)	
	Compare (measured) frequency/wavelength to the frequency/wavelength for a source on the Earth	(1)	
	States appropriate Doppler formula (consistent with mp1/mp2) and how it is used to calculate velocity	(1)	3
(b)	(Standard candles are stellar) objects of known luminosity	(1)	1
(c)	See $v = H_0 d$ and $v = d/t$ Therefore $t = 1/H_0$ (dependent mark)	(1) (1)	2
(d)(i)	If density less than critical value, expansion would continue for ever	(1)	
	If density greater than critical, expansion would stop and universe would contract again	(1)	
	If density equals critical value, expansion rate would decrease to zero but universe would not contract again	(1)	3
(d)(ii)	The mass of the universe is uncertain because of the amount of dark matter is uncertain	(1)	
	The value of the Hubble constant is uncertain	(1)	
	Or		
	The amount of dark matter (in the universe) is uncertain Since dark matter doesn't interact via the electromagnetic interaction	(1) (1)	
	Or		
	The value of the Hubble constant is uncertain Since measurements of distances to distant galaxies are uncertain	(1) (1)	2
	Total for question		13

Q10.

Question Number	Answer	Mark
	The only correct answer is D because there is relative motion of the objects away from each other so the wavelength is increased by the Doppler effect so the observed frequency is decreased A there is relative motion of the objects towards each other so the wavelength is decreased by the Doppler effect so the observed frequency is increased B there is no relative motion for the objects so there is no observed change in wavelength or frequency C there is relative motion of the objects towards each other so the wavelength is decreased by the Doppler effect so the observed frequency is increased	1

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • The fractional change in wavelength is proportional to the relative velocity of the source (1) • Hence the change in wavelength is proportional to the wavelength (1) **OR** • $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ and v and c are the same for all wavelengths **Or** $\frac{\Delta\lambda}{\lambda} = z$ and z is constant (1) • change in wavelength is proportional to the wavelength **Or** rearranges, e.g. $\Delta\lambda = x\lambda$ to demonstrate $\Delta\lambda$ is proportional to λ (1)		2

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • Estimate λ_{star} (1) (above 7×10^{-7} m) • Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with (1) 656 nm as denominator • $v = 3.8 \times 10^{7}$ m s^{-1} (1) (range 3.4×10^{7} m s^{-1} to 4.2×10^{7} m s^{-1}) • (Star is) moving away from the Earth (1) **Or** (star is) receding	Example of calculation $\frac{(7.40 \times 10^{-7} - 6.56 \times 10^{-7})}{6.56 \times 10^{-7}\ m} = \frac{v}{3.00 \times 10^{8}\ m\ s^{-1}}$ $\therefore v = \frac{0.84 \times 10^{-7}\ \text{m}}{6.56 \times 10^{-7}\ \text{m}} \times 3.00 \times 10^{8}\ \text{m s}^{-1}$ $\therefore v = 3.84 \times 10^{7}\ \text{m s}^{-1}$	4

Q3.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Gradient of graph determined (1) • $v = Hd$, so t = 1/H = 1/gradient (1) • $t = 4.7 \times 10^{17}$ s (1)	Example of calculation: Gradient= $\frac{(44000\text{-}1000)\ \text{km s}^{-1}}{(2.00\text{-}0.00)\times 10^{22}\ \text{km}} = 2.15\times 10^{-18}\ \text{s}^{-1}$ $t = \frac{1}{2.15\times 10^{-18}\ \text{s}^{-1}} = 4.65\times 10^{17}\ \text{s}$	3

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with $\lambda = 656.2$ nm (1) • $v = 9 \times 10^4$ m s^{-1} (1) • the star is moving towards the Earth (1)	Example of calculation: $v = \left(\frac{(656.2 - 656.0) \times 10^{-9}\text{ m}}{656.2 \times 10^{-9}\text{ m}}\right) \times 3.00 \times 10^8\text{ m s}^{-1}$ $= 9.14 \times 10^4\text{ m s}^{-1}$	3

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An answer that makes reference to the following: • because the helium atoms are moving, there is a change in frequency/ wavelength of the emitted light (1) • for particles moving away from the observer there will be an decrease in frequency and for particles moving towards the observer there will be an increase in frequency (1) OR for particles moving away from the observer there will be an increase in wavelength and for particles moving towards the observer there will be an decrease in wavelength (1)		**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)(1)	• use of $v/c = \Delta\lambda/\lambda$ • $v = 1530$ m s^{-1}	Example of calculation: v / 3 × 10^{8} m s^{-1} = 3 × 10^{-3} nm / 587 nm v = 1530 m s^{-1}	**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)(2)	• mass of helium atom = 4u • use of ½ $m \langle c^2 \rangle = 3/2\ kT$ • T = 375 K	Example of calculation: Mass of He atom = 4 × 1.66 × 10^{-27} kg = 6.64 × 10^{-27} kg ½ 6.64 × 10^{-27} kg × (1530 m s^{-1})^2 = 3/2 × 1.38 × 10^{-23} J K^{-1} × T T = 375 K	**(3)**

Q6.

Question Number	Answer		Mark
	(Observed frequency is less, so) source is receding (from Earth)	(1)	
	Use of $\frac{\Delta f}{f} = \frac{v}{c}$ Or $z = \frac{\Delta f}{f}$	(1)	
	$v = 1.5 \times 10^6\ \text{m s}^{-1}$ Or $z = 5.0 \times 10^{-3}$	(1)	3
	(min 2 sf answer required)		
	Example of calculation: $\Delta f = (4.547 \times 10^{14} - 4.570 \times 10^{14})\ \text{Hz} = (-)2.3 \times 10^{12}\ \text{Hz}$ $v = \frac{c\,\Delta f}{f} = \frac{3.0 \times 10^8\ \text{m s}^{-1} \times 2.3 \times 10^{12}\ \text{Hz}}{4.57 \times 10^{14}\ \text{Hz}} = 1.51 \times 10^6\ \text{m s}^{-1}$		
	Total for question		**3**

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	• The frequency/wavelength (of a line in the spectrum) emitted by the star must be measured **(1)** • Determine the difference between this frequency/wavelength and that emitted in the lab **(1)** • (The Doppler equation is used to) determine the speed of the star (relative to the Earth) $v/c = \Delta f/f_0$ or $v/c = \Delta\lambda/\lambda_0$ **(1)** • Clear indication (stated in words or via a formula) that v is positive/approaching when the frequency has increased and negative/receding when it has decreased **Or** corresponding statement about wavelength **(1)**	MP2 – accept in terms of difference between measured frequency/wavelength with average frequency/wavelength	**4**

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	• The wavelength change is bigger the further away the galaxies are **(1)** • The further away galaxies are the faster they are moving, so all distant galaxies are moving away from each other (and the universe is expanding) **(1)** • There is a large amount of scatter in Hubble's original data set. **(1)** • The original data set covers a very small range of distances [only the closest galaxies considered] **(1)** • Hence, on the basis of the original data, the conclusion drawn by Hubble was quite speculative **(1)**		**5**

Q9.

Question Number	Answer		Mark
(a)	Calculate gradient of line Identify gradient with H **Or** use of v = Hd for a point on the line Use of t = 1/H $t = 4.5 \times 10^{17}$ s (accept answers in range 4.2×10^{17} s to 4.8×10^{17} s) **Alternative method:** Pair of d, v values read from the line Values chosen from the upper end of the line Use of t = d/v $t = 4.5 \times 10^{17}$ s [$\pm 0.3 \times 10^{17}$ s] [$t = 1.4 \times 10^{10}$ yr [$\pm 0.1 \times 10^{10}$ yr] Example of calculation $H = \text{gradient} = \frac{(11000-0)\times 10^3 \text{ m s}^{-1}}{(50-0)\times 10^{23} \text{ m}} = 2.2\times 10^{-18} \text{ s}^{-1}$ $t = \frac{1}{H} = \frac{1}{2.2\times 10^{-18} \text{ s}^{-1}} = 4.5\times 10^{17} \text{ s}$	(1) (1) (1) (1) (1) (1) (1) (1)	4
* (b)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** Measure wavelength of light (from the galaxy) Compare it to the wavelength for a source on the Earth Reference to spectral line **or** line spectrum Reference to Doppler effect/shift **Or** redshift *v* is found from: fractional change in wavelength equals ratio of speed of source to speed of light **Or** see reference to $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ with terms defined **Or** see reference to $z = \frac{v}{c}$ with terms defined [accept answers in terms of frequency rather than wavelength]	 (1) (1) (1) (1) (1)	5
*(c)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** **Max 3** (Due to the) difficulty in making accurate measurements of distances to galaxies Hubble constant has a large uncertainty **Or** age = 1/H may not be valid as gravity is changing the expansion rate Because of the existence of dark matter Values of the (average) density/mass of the universe have a large uncertainty [accept not known] (Hence) measurements of the critical density of the Universe have a large uncertainty Dark energy may mean we don't understand gravity as well as we thought we did (so it's hard to predict how gravity will determine the ultimate fate)	 (1) (1) (1) (1) (1) (1)	3

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Q10.

Question Number	Answer	Mark
	Galaxies are receding **(1)** **O**r galaxies are moving away (from us and from each other) **(1)** **T**he greater the distance the greater the velocity **(1)** The universe is expanding	**3**
	Total for question	**3**

Q11.

Question Number	Answer	Mark
	D – $\frac{(656.3 - 654.9)}{654.9} \times 3 \times 10^8 \text{ m s}^{-1}$	**1**
	Incorrect Answers: correct method: $\frac{change\ in\ wavelength}{wavelength\ in\ laboratory} \times speed\ of\ light$ A – uses $\frac{wavelength\ from\ star}{wavelength\ in\ laboratory} \times speed\ of\ light$ B – uses $\frac{wavelength\ in\ laboratory}{change\ in\ wavelength} \times speed\ of\ light$ C – uses $\frac{wavelength\ in\ laboratory}{wavelength\ from\ star} \times speed\ of\ light$	

Q12.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is C because the correct method for a nearby star is parallax, for a nearby galaxy is standard candle and for a very distant galaxy is red shift A is not correct because only the nearby star method is correct B is not correct because only the nearby galaxy method is correct D is not correct because none of the methods are correct	**1**

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Q13.

Question number	Acceptable answers	Additional guidance	Mark
(i)	**Either** • When x = R_0, F = GMm/R_0^2 **(1)** • F = $GMmR_0/R_0^3$ so k = $m\omega^2 = GMm/R_0^3$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • From graph F=-(g/R_o)r **(1)** • From which $\omega = \sqrt{(g/R_0)}$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • So $T = 2\pi\sqrt{(R_o^3/g)}$ **(1)**		**4**

Question number	Acceptable answers	Additional guidance	Mark
(ii)	**Either** Centripetal force = $mv^2/R_0 = GMm/R_0^2$ **(1)** • $4\pi^2 R_0^2/ T^2R_0 = GM/R_0^2$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • $mg = mv^2/R_0 = m\,\omega^2R_0$ **(1)** • So $\omega = \sqrt{(g/R_0)}$ **(1)** • $T = 2\pi/\omega = 2\pi\sqrt{(R_0/g)}$ **(1)**		**3**

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use total mass / mass of D ion **(1)** • Use of $pV = NkT$ **(1)** • $p = 2.8 \times 10^4$ Pa **(1)**	Example of calculation $N = 5.0 \times 10^{-6}$ kg / 3.3×10^{-27} kg = 1.5×10^{21} $p = 1.5 \times 10^{21} \times 1.38 \times 10^{-23}$ J K^{-1} × 130 000 000 K / 98 m^3 $= 2.77 \times 10^4$ Pa	**3**
(ii)	• Use of $\frac{1}{2}\, m\, \langle c^2\rangle = 3/2\, kT$ **Or** $pV = 1/3\,(Nm\langle c^2\rangle)$ (ecf for N and p from (i)) **(1)** • $\sqrt{\langle c^2\rangle} = 1.3 \times 10^6$ m s^{-1} **(1)**	Example of calculation $\frac{1}{2}\, m\, \langle c^2\rangle = 3/2\, kT$ $\frac{1}{2} \times (3.3 \times 10^{-27}$ kg) × $\langle c^2\rangle = 3/2 \times 1.38 \times 10^{-23}$ J K^{-1} × 130 000 000 K $\langle c^2\rangle = 1.6 \times 10^{12}$ m^2 s^{-2} $\sqrt{\langle c^2\rangle} = 1.28 \times 10^6$ m s^{-1}	**2**
(iii)	• Use of $\Delta\lambda / \lambda = v/c$ to determine $\Delta\lambda$ **(1)** • Adds shift to original wavelength **(1)** • 1.075×10^{-6} m **(1)**	Example of calculation $\Delta\lambda / 1.064 \times 10^{-6}$ m = 15×10^6 m s^{-1}/3.00×10^8 m s^{-1} $\Delta\lambda = 5.3 \times 10^{-9}$ m $\lambda + 2\Delta\lambda = 1.075 \times 10^{-6}$ m	**3**

Q15.

Question Number	Answer		Mark
(a)(i)	Redshift is the (fractional) increase in wavelength received (by an observer)	(1)	
	Due to source and observer receding (from each other)	(1)	2
6(a)(ii)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate**		
	Measure frequency/wavelength of light (from the galaxy)	(1)	
	Compare (measured) frequency/wavelength to the frequency/wavelength for a source on the Earth	(1)	
	States appropriate Doppler formula (consistent with mp1/mp2) and how it is used to calculate velocity	(1)	3
(b)	(Standard candles are stellar) objects of known luminosity	(1)	1
(c)	See $v = H_0 d$ and $v = d/t$	(1)	
	Therefore $t = 1/H_0$ (dependent mark)	(1)	2
(d)(i)	If density less than critical value, expansion would continue for ever	(1)	
	If density greater than critical, expansion would stop and universe would contract again	(1)	
	If density equals critical value, expansion rate would decrease to zero but universe would not contract again	(1)	3
(d)(ii)	The mass of the universe is uncertain because of the amount of dark matter is uncertain	(1)	
	The value of the Hubble constant is uncertain	(1)	
	Or		
	The amount of dark matter (in the universe) is uncertain	(1)	
	Since dark matter doesn't interact via the electromagnetic interaction	(1)	
	Or		
	The value of the Hubble constant is uncertain		
	Since measurements of distances to distant galaxies are uncertain	(1)	
		(1)	2
	Total for question		**13**

Q16.

Question Number	Answer	Mark
	There is a red shift [accept Doppler shift] (1) The galaxy is receding **Or** the galaxy is moving away from us (1) [Do not accept "the universe is expanding"]	**2**
	Total for question	**2**

Q17.

Question number	Acceptable answers	Additional guidance	Mark
	• Force on object = mg (local g) **(1)** • Force is proportional to displacement **(1)** • Force acts in the opposite direction to the displacement **(1)** • Therefore we can say $F = -kx$, so the condition for SHM is met and the prediction is correct **(1)**		**4**

Q18.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: **(1)** • Hubble is for cosmological distances **(1)** • is not suitable since S2 is in our galaxy **(1)** • trigonometrical parallax is suitable for local stars because the parallax angles produced are large enough to measure accurately	e.g. to distant galaxies	**3**

Q19.

Question Number	Answer		Mark
(a)(i)	(A standard candle is) an object of known luminosity	**(1)**	**1**
(a)(ii)	Flux/brightness/intensity of standard candle is measured Inverse square law used (to calculate distance to standard candle) [Reference to measurement of apparent magnitude of star, m, and distance calculated using $m - M = 5\log(d/10\text{ pc})$ can score 2 marks]	**(1)** **(1)**	**2**
(b)(i)	An increase in the wavelength (of radiation) received from a receding source [accept in terms of a decrease in the frequency]	**(1)**	**1**
(b)(ii)	Use of $z = v/c$ and $v = H_0 d$ $[z = H_0 d/c]$ $d = 1.7 \times 10^{25}$ m <u>Example of calculation:</u> $v = zc = 0.12 \times 3\times10^8$ m s^{-1} $= 3.6 \times10^7$ m s^{-1} $d = v/H = 3.6 \times10^7$ m s^{-1}/2.1×10^{-18} s^{-1} $= 1.71 \times 10^{25}$ m	**(1)** **(1)**	**2**
***(c)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) **Max 3** Dark matter has mass but does not emit e-m radiation [accept light] (Dark matter proposed when) observations of galaxies indicated that they must contain more matter than could be seen. The existence of dark matter will increase the (average) density of the universe This may make it more likely that the universe is closed [accept will contract **Or** end with a "Big Crunch"] **Or** Idea that this may make the ultimate fate of the Universe less certain	**(1)** **(1)** **(1)** **(1)**	**3**
(d)	**Max 2** The universe started from a small initial point [accept Big Bang] Idea that universe has a finite age Idea that (observable universe is finite because) we can only see as far as (speed of light) × (age of universe) **Or** light reaching us must have travelled a finite distance since the Big Bang **Or** some parts of the universe are so distant, light has not had time to reach us yet	**(1)** **(1)** **(1)**	**2**
	Total for question		**11**

Q20.

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Question Number	Acceptable answers	Additional guidance	
(a)	• Object of known luminosity **(1)**		1

Question Number	Acceptable answers	Additional guidance	
(b)	• The (parallax) angle becomes very small **(1)** **Or** the diameter of the Earth's orbit is very small • Giving a (very) large percentage uncertainty **(1)**		2

Question Number	Acceptable answers	Additional guidance	
(c)	• Measure change in wavelength / frequency **(1)** • Determine relative velocity using redshift formula **(1)** • Then apply $v = H_0 d$ **(1)**		3

Mark Scheme

Q1.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Gradient of graph determined	(1)	Example of calculation: Gradient= $\frac{(44000\text{-}1000)\ \text{km s}^{-1}}{(2.00\text{-}0.00)\times10^{22}\ \text{km}}=2.15\times10^{-18}\text{s}^{-1}$	
	• $v = Hd$, so t = $1/H$ = 1/gradient	(1)		
	• $t = 4.7 \times 10^{17}$ s	(1)	$t=\frac{1}{2.15\times10^{-18}\text{s}^{-1}}=4.65\times10^{17}\text{s}$	3

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
	• The wavelength change is bigger the further away the galaxies are **(1)** • The further away galaxies are the faster they are moving, so all distant galaxies are moving away from each other (and the universe is expanding) **(1)** • There is a large amount of scatter in Hubble's original data set. **(1)** • The original data set covers a very small range of distances [only the closest galaxies considered] **(1)** • Hence, on the basis of the original data, the conclusion drawn by Hubble was quite speculative **(1)**		5

Q3.

Question number	Acceptable answers	Additional guidance	Mark
(i)	**Either** • When x = R_0, F = GMm/R_0^2 **(1)** • F = $GMmR_0/R_0^3$ so k = $m\omega^2 = GMm/R_0^3$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • From graph F=-(g/R_o)r **(1)** • From which $\omega = \sqrt{(g/R_0)}$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • So $T = 2\pi\sqrt{(R_o^3/g)}$ **(1)**		**4**

Question number	Acceptable answers	Additional guidance	Mark
(ii)	**Either** Centripetal force = $mv^2/R_0 = GMm/R_0^2$ **(1)** • $4\pi^2 R_0^2/ T^2R_0 = GM/R_0^2$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • $mg = mv^2/R_0 = m\ \omega^2R_0$ **(1)** • So $\omega = \sqrt{(g/R_0)}$ **(1)** • $T = 2\pi/\omega = 2\pi\sqrt{(R_0/g)}$ **(1)**		**3**

Q4.

Question Number	Answer		Mark
(a)(i)	Redshift is the (fractional) increase in wavelength received (by an observer)	(1)	
	Due to source and observer receding (from each other)	(1)	2
6(a)(ii)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate**		
	Measure frequency/wavelength of light (from the galaxy)	(1)	
	Compare (measured) frequency/wavelength to the frequency/wavelength for a source on the Earth	(1)	
	States appropriate Doppler formula (consistent with mp1/mp2) and how it is used to calculate velocity	(1)	3
(b)	(Standard candles are stellar) objects of known luminosity	(1)	1
(c)	See $v = H_0 d$ and $v = d/t$	(1)	
	Therefore $t = 1/H_0$ (dependent mark)	(1)	2
(d)(i)	If density less than critical value, expansion would continue for ever	(1)	
	If density greater than critical, expansion would stop and universe would contract again	(1)	
	If density equals critical value, expansion rate would decrease to zero but universe would not contract again	(1)	3
(d)(ii)	The mass of the universe is uncertain because of the amount of dark matter is uncertain	(1)	
	The value of the Hubble constant is uncertain	(1)	
	Or		
	The amount of dark matter (in the universe) is uncertain	(1)	
	Since dark matter doesn't interact via the electromagnetic interaction	(1)	
	Or		
	The value of the Hubble constant is uncertain		
	Since measurements of distances to distant galaxies are uncertain	(1)	
		(1)	2
	Total for question		**13**

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