WJEC
CBAC

GCE MARKING SCHEME

PHYSICS (NEW)
AS/Advanced

JANUARY 2010

INTRODUCTION

The marking schemes which follow were the ones used by the WJEC for the January 2010 papers in the GCE PHYSICS examination. They were finalised after detailed discussion at an examiners' conferences by all the examiners involved in the assessment. The conferences were held shortly after the papers were taken so that reference could be made to the full range of candidates' responses, with photocopied scripts forming the basis of discussion. The aim of the conferences was to ensure that the marking scheme was interpreted and applied in the same way by all examiners.

It is hoped that this information will be of assistance to centres but it is recognised at the same time that, without the benefit of participation in the examiners' conference, teachers may have different views on certain matters of detail or interpretation.

The WJEC regrets that it cannot enter into any discussion or correspondence about these marking schemes.

Notes on the interpretation of these marking schemes

The marking schemes, whilst reasonably complete do not give **all** the answers which were credited by the examiners. It is hoped that the schemes are self-explanatory, though they will need to be read alongside the question papers. The following clarifications may be of use:

Statements in brackets [ ] are exemplification, alternatives, acceptable ranges, e.g. $3.8\ [\pm 0.3] \times 10^{-19}$ J **or** statements which, whilst desirable in an answer were not required on this occasion for full marks. [accept….] indicates that, whilst not a good answer, it was accepted on this occasion.

The numbers in parentheses ( ) are the marks, usually 1, for each response.

e.c.f. stands for *error carried forward,* and indicates that the results of a previous (incorrect) calculation will be treated as correct for the current section. i.e. the mistake will only be penalised once.

The expression [or by impl.] indicates that the mark is credited when subsequent credit-worthy working or answer demonstrates that this idea/equation has been used.

In general the physics of the answer needs to be correct but specific expressions or methods are often not required. The expression [or equiv.] emphasises that the particular idea, could be expressed in several different ways.

Incorrect or absent units are not always penalised, but they are present in the mark scheme for completeness. Where ((**unit**)) appears it indicates that the unit is required for the mark to be awarded but attracts no separate mark. A (1) following the unit, in addition to a (1) following the numerical part of the answer, indicates that the unit itself attracts a mark.

<u>Example</u>: 25 GPa (1) ((**unit**)) indicates that the unit (or correct alternative. e.g. $2{\cdot}5 \times 10^{10}$ N m^{-2}) is a requirement for the mark;

25 (1) GPa (1) indicates that the numerical part of the answer [$2{\cdot}5 \times 10^{10}$] and the unit Pa each attract a mark. In this case, an answer of 25 GN would be awarded the first mark but not the second, it being considered that the SI multiplier is numerical.

Unless otherwise stated, no penalties for excessive significant figures are applied in these papers. Significant figures are usually assessed only in the practical units.
N.B. This Mark Scheme is not a set of Model Answers.

PH1 Mark Scheme – January 2010

Question			Marking details	Marks Available
1.	*(a)*		Flow of charge [accept ….charge/ions] **or** $\frac{[\Delta]Q}{[\Delta]t}$, if the symbols defined	1
	(b)	(i)	Sum of areas of triangle and rectangle areas attempted [or reasonable attempt at area of trapezium] (1) Q = 3.0 C ((**unit**))(1)	2
		(ii)	No. of electrons = $\frac{3.0\text{(e.c.f.)}}{1.6\times10^{-19}(1)}$ = 1.9 × 10^{-19} (1) [1st mark div by e]	2
		(iii)	I = 1.2(0) A (from graph) (1); $v = \frac{I}{nAe}$ [manipulation shown – could be in following substitution – or by impl.](e.c.f. on I](1) = 3.75 × 10^{-5} m s^{-1} [accept 3.8 × 10^{-5} m s^{-1}] (e.c.f. on I) (1)	3 **[8]**
2.	*(a)*		Free [or equiv, e.g. conducting / moving / delocalised] electrons (1) collide / interact / hindered [by] (1) with atoms / ions of metal conductor / lattice ["particles" b.o.d.](1)	3
	(b)	(i)	I. [0 – 2 V]: Resistance constant / changes by v. small amount II. [2 – 8 V]: Resistance increases	1 1
		(ii)	**Either** $R_{\text{bulb}} = \frac{6.0}{0.8(1)} = 7.5\ \Omega$ (1) Total resistance = 5 Ω (1) [ecf] $\left[\text{Correct use of } \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}\right]$ I = 1.2 A (1) [ecf on R] **Or** I through 15Ω = $\frac{6.0}{15}$ (1)= 0.4 A (1) I through bulb = 0.8 A (1) ∴ Total current = 1.2 A (1)	4
		(iii)	Subst in $P = I^2R$ [ecf on R and I] **or** in $P = \frac{V^2}{R}$ [ecf on R only] **or** $P=IV$ [ecf on I only] (1) P = 7.2 W (1)	2 **[11]**

Question			Marking details	Marks Available
3.	*(a)*		The electrical (potential) energy transferred [or work done] *per coulomb / unit charge* passing through the cell [Underlined (1); *italic* (1)]	2
	(b)		Voltmeter shown in parallel with cell [outside the dotted line – accept inside the line if outside the cell/i.r combination] [Accept equivalent, e.g. connected in parallel with resistor]	1
	(c)		All points correctly plotted (2) [–1 per mistake, min 0] Line correctly drawn [with extrapolation just to V axis] (1)	3
	(d)	(i)	[e.m.f. =] 1.6 V	1
		(ii)	gradient attempted [or by impl.](1); r = 0.33 Ω / 0.3 Ω / $^1/_3$Ω (1)	2
				[10]
4.	*(a)*	(i)	$\frac{\text{Total distance}}{\text{[Total] time}}$ [or equiv.] [**Not** rate of change of distance]	1
		(ii)	Time for the whole journey = 3 h + 4 h = 7 h (1) [or 25 200 s] Mean speed $= \frac{480(1)}{7}\left[\frac{480000}{25200}\right]$ =68.6 km h^{-1} (1)[accept 69 – not 70]	3
	(b)	(i)	Forward force labelled Driving / engine force **and** reverse force labelled Friction / drag / air resistance]	1
		(ii)	Maximum at t = 0 (s) [accept: starts high at t = 0](1) Decreases (1) to zero [after 8 s] (1)	3
		(iii)	$a = \frac{\Delta v\text{(from tangent)}}{\Delta t\text{ (from tangent)}}$ (= 2.75 [accept 2.6 – 2.9] m s^{-1}) (1) $\sum F = ma$ / $\sum F$ = 350 × 2.75(ecf) (1)= 962.5 [accept 910 – 1015] N (1)	3
	(c)	(i)	Force × distance (moved) (1) in the direction of the force (1) [or equivalent, e.g. component of force in the direction of motion × distance moved, $Fd\cos\theta$ if symbols defined]	2
		(ii)	Power $P = \frac{\text{work done}}{\text{time}}$ or $P = \frac{Fd}{t}$ (1) d/t identified with v (1) [by impl. if F×d / t used to define power]	2
		(iii)	$F = \frac{40\times10^3}{18}$ [=2200 N]	1
	(d)	(i)	Energy cannot be created or destroyed only changed from one form to another.	1
		(ii)	Brake pads and wheel discs heat up (1) [accept k.e. → heat energy] Reference to particles' gaining energy (1)	2
				[20]

Question			Marking details	Marks Available
5.	*(a)*	(i)	Wire with rule positioned (1) and <u>labelled</u> moving pointer / jockey / croc clip (1) **Either c**orrectly positioned ohm-meter with no power supply **or** correctly position ammeter and voltmeter with power supply (1)	3
		(ii)	[Different] length[s] of wire (1) **Either** measure V and I **or** measure / read R (1)	2
		(iii)	Diameter of wire [not radius or csa by accept "thickness"] with micrometer / vernier calliper	1
		(iv)	cross-sectional area fro πr^2 or $\pi(d/2)^2$ (1) graph of R against l [**or** mean value of R/l] (1) ρ = gradient × [cs]a [**or** mean value of R/l × csa] (1) [NB $R = V/I$ given here can be used to credit 2nd mark of (ii)] [NB Finding R for a measured length and [cs] area and then ρ calculated → 1 only]	3
	(b)	(i)	$R \propto l$ (1) $\therefore$ R <u>increases</u> as strain gauge gets longer (1) $R \propto {}^1/A$ (1) $\therefore$ R <u>increases</u> as the strain gauge gets thinner (1) [**or** $R = \frac{\rho l}{A}$ or $\rho = \frac{RA}{l}$ (1), A increases & l decreases (1) ρ doesn't change /constant (1) so resistance increases (1)]	4
		(ii)	[csa =] $0.2 \times 10^{-3} \times 0.0012 \times 10^{-3}$ [or equiv.] (1) $\rho = 4.9 \times 10^{-7}\ \Omega$ m ((**unit**)) (1) [ecf from csa calculation] [ecf on powers of 10 in both A and l]	2
		(iii)	**Either** $1.6 = \frac{650}{650 + R} \times 6$ (1) Manipulation (1); R = 1788 Ω (1) **Or** $I = \frac{1.6}{650}$ (=2.46 × 10^{-3} A) (1) $R = \frac{(6-1.6)(1)}{2.46 \times 10^{-3}}$ = 1788 Ω (1)	3
				[18]

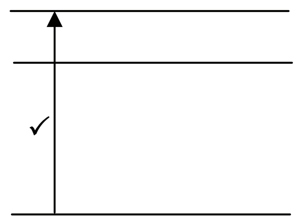
Question			Marking details	Marks Available
6.	*(a)*	(i)	Horizontal arrow [by eye] to right, close to **A**, labelled **D**. (1)	
		(ii)	Vertically downwards arrow at **A** labelled **F**. (1)[NB if other force(s) labelled, s.i.f. $\rightarrow$0]	2
	(b)	(i)	$U_{\text{H}} = \frac{4.50}{1.50} \left(= 3.0 \text{ m s}^{-1}\right)$	1
		(ii)	Use of relevant equation, e.g. $v = u + at$ or $v^2 = u^2 + 2ax$ (1) [or by impl.] Correct subst e.g. $0 = u - 9.81 \times 0.75$ or $0 = u^2 - 2 \times 9.81 \times 2.75$ (1) [or by impl.] Answer U = 7.3 / 7.35 / 7.4 m s^{-1} (1)	3
		(iii)	$U = \sqrt{3.0^2 + 7.4^2}$ [or $U^2 = 3^2 + 7.4^2$] (1) [e.c.f. on both velocities] = 7.9 – 8.0 m s^{-1} (1)	2
	(c)	(i)	$E_{\text{total}} = mgh + \frac{1}{2} m v_{\text{H}}^2$ [or by impl.] [Accept E_{total} = P.E. + K.E.] (1) $= 6.0 \times 9.81 \times 2.75 + \frac{1}{2} \times 6.0 \times 3.0^2$ [e.c.f. on v_{H}] (1) [subst] = 189 J (1) [NB If only PE considered then 0]	3
		(ii)	Extreme points of trajectory **both** marked with a **K**.	1
		(iii)	$\frac{1}{2} m U^2 = 189$ (1) [e.c.f.] [accept KE = 189 J ecf] U = 7.9 m s^{-1} (1)	2
				[14]

PH2 Mark Scheme – January 2010

Question			Marking details	Marks Available
1	*(a)*	(i)	I. 2 arrows drawn upwards at right angles to wave fronts	1
			II. The waves travel more slowly in the shallow water (1) as the propagation direction bends towards the normal (or equiv) (1)	2
		(ii)	I. Wavelength = 8 [±1] mm	1
			II. $f = \frac{0.33\text{ m s}^{-1}}{0.008\text{ m}}$ (1) [or by impl.] (e.c.f. on λ) = 40 or 41 Hz (1) [–1 on wrong power of 10]	2
			III. Attempt clearly based upon unchanged f <u>or</u> $\frac{v_s}{v_d} = \frac{\lambda_s}{\lambda_d}$ (1) [or by impl.] v = 0.21 [±0.02 m s^{-1}] (e.c.f. on f) (1)	2
	(b)	(i)	Total internal reflection	1
		(ii)	$1.58\sin 72^\circ = n_{clad}\sin 90^\circ$ [or by impl.] (1) $n_{clad} = 1.58\sin 72^\circ$ <u>or</u> $\sin 90^\circ = 1$ <u>or</u> by impl. (1) $n_{clad} = 1.50$ (1) [Angles transposed, leading to n = 1.64, or other transposition errors → 1 mark only]	3
		(iii)	Light takes longer by zigzag paths [accept 'multimode dispersion'] [Accept – different paths give different times] (1) A piece of data will be 'smeared out' over time on arrival <u>or</u> may overlap other pieces of data (1) [Accept 'pulse broadening' only if first mark gained by reference to zigzag paths, i.e. **not** 'multimode dispersion' + 'pulse broadening' only (2)]	2
				[14]

Question			Marking details	Marks Available
2.	*(a)*	(i)	At [centres of] bright fringes: • Path lengths from slits differ by 0, λ, 2λ... [if sources in phase] • Waves arrive in phase or sketch graphs of in-phase waves • Waves interfere constructively <u>or</u> displacements add to make larger displacement. • Assume slits act as coherent sources or waves diffract at slits any 4 × (1)	4
		(ii)	Separation of centres of fringes $= \frac{4.0}{3}$ mm / 1.3 mm / 1.33 mm [or equiv, or by impl.] (1) Correct data substitution into $\lambda = \frac{ay}{D}$ ignoring factors of 10 [e.c.f.] (1) $\lambda = 6.3 \times 10^{-7}$ m (1)	3
	(b)	(i)	2[.00] × 10^{-6} m	1
		(ii)	Attempt to use $n\lambda = d\sin\theta$ with $d = 2.00 \times 10^{-6}$ m [e.c.f.] (1) $\theta = 72°$ (1) $n = 3$ (1) $\lambda = 6.3 \times 10^{-7}$ m (1) [e.c.f. only on d from *(b)*(i)]	4
	(c)		More uncertainty with Young's method (1).... because..... **either** fringe separation is small and difficult to measure [whereas grating beams are well spaced] **or** fringes are not sharp compared to the beams (1) [accept: *d* can be measured more accurately for grating [because there are more slits]	2
				[14]

Question			Marking details	Marks Available
3	*(a)*	(i)	… in phase (1) … in antiphase [accept <u>completely</u> or 180° or π out of phase] (1)	2
		(ii)	Use stroboscope (1) and adjust flash frequency for slow motion / expect to see **A** moving up as **C** moves down etc. (1) [**Or:** Use a video camera and replay in slow motion / expect to see **A** moving up as **C** moves down etc.]	2
	(b)	(i)	**Either:**<u>Amplitude</u> constant [or falls off] for progressive wave (1) as we go through the medium; goes up and down [regularly] form stationary wave (1) **Or:** <u>Phase</u> changes steadily with distance for progressive waves (1); reverses at nodes [otherwise constant] form stationary waves (1) ["Stationary waves have nodes, progressive waves don't" → 1]	2
		(ii)	Reflections give rise to waves propagating in both directions (1); interference between these [progressive] waves gives stationary wave (1)	2
	(c)	(i)	0.6 m	1
		(ii)	30 m s^{-1} ((**unit**))	1
				[10]
4.	*(a)*	(i)	<u>Photon</u> energy	1
		(ii)	$E_{k\ max}$ is the maximum KE of emitted electron (1) ϕ is the minimum energy for an electron to escape (1). What is left over of the photon's energy after the escape is its kinetic energy. (1)	3
	(b)	(i)	Graph: Points [±0.2 divisions] (1); line [not necessarily extrapolated] (1)	2
		(ii)	I. 3.8 [± 0.2] × 10^{-19} J II. $\frac{(4.04-0.79)\times10^{-19}\,\text{J}}{(11.8-6.9)\times10^{14}\,\text{Hz}}\left[\text{or } \frac{\Delta y}{\Delta x} \text{ from graph}\right]$(1) = 6.6 [± 0.4]× 10^{-34} Js (1) NB. Must be value from working.	1 2
		(iii)	Graph line drawn with same slope (1) and to left of / above that for sodium (1)	2
				[11]

Question			Marking details	Marks Available
5	*(a)*		$\Delta E = \frac{hc}{\lambda}$ [**or** $\Delta E = hf$ **and** $c = f\lambda$] [or by impl.] (1) $\lambda = 6.95 \times 10^{-7}$ m (1)	2
	(b)	(i)	Absorption [accept excitation]	1
		(ii)	Increases atom's [accept electron's]energy [accept 'excites atom' unless excitation credited in part (i)](1)	1
	(c)	(i)	Stimulated emission	1
		(ii)	Any 2 × 1 of: frequency [or wavelength or energy] / phase / propagation direction / polarisation	2
	(d)	(i)	More electrons in the higher (middle) level than the lower [or ground]	1
		(ii)	Arrow shown on Process B from lowest level to top level. 	1
		(iii)	Shorter time at top level (1) to maintain population of middle level (1)…	2
				[11]
6	*(a)*		Charge = $\frac{2}{3}$ [e] + $-\frac{1}{3}$ [e] + $-\frac{1}{3}$ [e] = 0 [or equiv.] [**or** No other combination of 3 u and d quarks gives zero charge]	1
	(b)	(i)	π^-: $-\frac{1}{3}$ [e] + $-\frac{2}{3}$ [e] [or equiv.] = –e [or –1] (1) Δ^-: 3 × $-\frac{1}{3}$ [e] = –e [or –1] (1)	2
		(ii)	A meson is a quark-antiquark (1) pairing. A baryon is a triplet of quarks [accept antiquarks] (1)	2
	(c)	(i)	I. 0 → 1 + (–1) or equiv. II. 3 → 2 + 1 or equiv.	2
		(ii)	u and d individually conserved **or** lifetime too short [accept no ν_e involvement]	1
	(d)	(i)	uuu	1
		(ii)	π must be $u\bar{d}$ [because charge must be conserved **or** because u and d numbers are individually conserved].	1
				[9]

Question			Marking details	Marks Available
7	*(a)*		λ_{max} = 950 [± 50] nm [or by impl.] (1) $T = \dfrac{2.90 \times 10^{-3}\ \text{m K}}{950 \times 10^{-9}\ \text{m}}$ (1) [ecf on λ_{max}] = 3050 K (1)	3
	(b)	(i)	Spectral intensity [far] greater at 700 nm [than at 400 nm].	1
		(ii)	Infrared	1
		(iii)	I. peak / around 900 – 950 nm II. λ_{max} = 550 nm [accept 500 – 600 nm](1) T = 5300 K (1) [e.c.f. from λ_{max} but only if λ_{max} between 400 and 700 nm]	1 2
	(c)		knowledge of meaning of symbols in $P = \sigma A T^4$ demonstrated (1) $A = 4\pi \times (1.01 \times 10^8\ \text{m})^2$ [$=1.28 \times 10^{17}\ \text{m}^2$] (1) $P = 6.3 \times 10^{23}$ W ((**unit**))(1) [e.c.f. on T from *(a)*] [1 mark lost if answer adrift by a factor of π or 2^n, or if the answer to *(b)*(iii)II used instead of 3000 K]	3
				[11]

PH4 Mark Scheme – January 2010

<table>
<tr><th colspan="3">Question</th><th>Marking details</th><th>Marks Available</th></tr>
<tr><td>1</td><td>(a)</td><td></td><td>Acceleration $\propto$ displacement [from a fixed point] (1) and directed towards a fixed point (1)
Or $a = [-]\omega^2 x$ (1); – sign and defined a and x, ω^2 a constant(1)</td><td>2</td></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td>$T = 2\pi\sqrt{\frac{m}{k}}$ [or by impl.](1)
$T^2 = 4\pi^2 \frac{m}{k}$, i.e. correct squaring [or by impl.](1)
$m = 0.127$ kg (1)</td><td>3</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>$\omega\left[= \frac{2\pi}{T}\right] = \frac{2\pi}{0.42\text{ s}}$ ✓[=14.96 [rad] s^{-1}]</td><td>1</td></tr>
<tr><td></td><td>(c)</td><td>(i)</td><td>$v_{max} = \omega A$ (subs)(1) = 0.194 m s^{-1} [accept 0.19 or 0.20] (1)</td><td>2</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>$a_{max} = [-]\omega^2 A$ (subs)(1) = 2.91 m s^{-2} (1)
[no penalty for minus sign in answer; no 2nd penalty for 10^2 error]</td><td>2</td></tr>
<tr><td></td><td>(d)</td><td>(i)</td><td>$^T/_4$ or 0.105 s</td><td>1</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>Either
$a = [-]\ 2.91 \sin \omega t$ (1) [or impl.]
$\omega t = \sin^{-1}\left(\frac{2.9}{2.91}\right)$ (1) [or impl.]
$t = 0.054$ s (1)
or
$a = -\omega^2 x \rightarrow x = 0.0094$ m (1)
$0.0094 = 0.13 \sin \omega t$ (subs) (1)
$t = 0.054$ s (1)
[–0.054 s loses 2nd mark, or equivalent wrong sector slip, e.g. 4.2 – 0.054 or even 2.1 – 0.054 etc.]</td><td>3

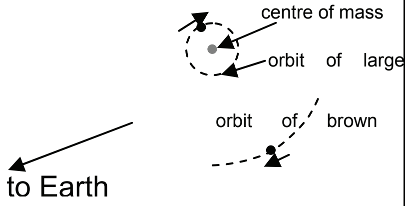
[14]</td></tr>
<tr><td>2</td><td>(a)</td><td></td><td>$p\left[= \frac{h}{\lambda}\right] = \frac{6.63\times10^{-34}\text{ J s}}{620\times10^{-9}\text{ m}}$ (✓) [= 1.07 × 10^{-27} kg m s^{-1}]</td><td>1</td></tr>
<tr><td></td><td>(b)</td><td></td><td>1.1 × 10^{-27} = [±] 1.1 × 10^{-27} + mv [i.e. accept incorrect sign] (1)
2.2 × 10^{-27} = 1.67 × 10^{-27} v (1)
v = 1.28 m s^{-1} (1)
[mv = 1.1 × 10^{-27} → v = 0.64 m s^{-1} – 1 mark only]</td><td>3</td></tr>
<tr><td></td><td>(c)</td><td>(i)</td><td>more energy after collision (1)
since photon energies are the same / energy increased by hydrogen KE or $\frac{1}{2}mv^2$ (1)</td><td>2</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>reflected photon has longer wavelength or red shift occurs
[or converse argument or frequency argument]</td><td>1

[7]</td></tr>
</table>

Question			Marking details	Marks Available
3	*(a)*		$pV = nRT$ (**subs**)(1) $n = \frac{60\times10^3\times0.05}{8.31\times278}$ (1) [=1.2986]	2
	(b)	(i)	**Either** $p = \frac{1}{3}\rho\overline{c^2}$ (1)* $\rho = \frac{m}{V}$ or $\frac{0.171}{0.05}$ (1) $c_{rms} = 229$ m s^{-1} (1) **or** $pV = \frac{1}{3}Nm\overline{c^2}$ (1) $v = 0.05$ m^3 **and** $Nm = 0.171$ (1) $c_{rms} = 229$ m s^{-1} (1) * Mark lost for incorrect substitution (e.g. of ρ) unless final root taken.	3
		(ii)	Division of m by 1.3 (1) Molar mass =0.132 kg / 132 g ((**unit**)) (1)	2 **[7]**
4.	*(a)*		ΔU – <u>change</u> / <u>increase</u> in *internal energy* Q – *Heat* supplied <u>to the gas /system</u> W – *Work* <u>done by the gas / system</u> Marking – all *italic* terms (1); all <u>underlined</u> terms (1)	2
	(b)	(i)	$W = p\Delta V$ **or** area under graph (1) $= 60\ 000 \times 50 \times 10^{-3}$ $= 3\ 000$ J (1)	2
		(ii)	Use of ΔT or $U_2 - U_1$ (1) $\Delta U = 4\ 500$ J (1)	2
	(c)	(i)	0	1
		(ii)	Temperature decreases / gas cools / ΔU –ve (1) Heat flows out / Q –ve (1) [**not** 'decrease in heat']	2
	(d)	(i)	Returns to same temperature / point / p, V, T (1) [**or** internal energy depends only on T [accept p, V, T]]	1
		(ii)	attempt at closed area or AB – CD (1) [or by impl.] W [= 20 000 × 0.05] = 1000 J (1) Q = 1000 J (1)	3 **[13]**

Question			Marking details	Marks Available
5	*(a)*	(i)	$g = \frac{GM}{r^2}$ (1) (**subs**) = 1.63 m s^{-2} / N kg^{-1} ((**unit**)) (1)	2
		(ii)	$F = mg$ **or** $F = \frac{GMm}{r^2}$ [or by impl.] (1) F = 3.25 N (1)	2
	(b)	(i)	KE = [½ mv^2] = 1.96 MJ	1
		(ii)	Gravitational PE = [–] $\frac{GMm}{r}$ (**subs**)[**or** $V = -\frac{GM}{r}$ **and** PE = mV] (1) $= -\frac{6.67\times10^{-11}\times7.35\times10^{22}\times2}{1.74\times10^{6}}$ (1) [= –5.635 MJ] [no sign penalty here]	2
		(iii)	Total incident energy = –3.7 MJ [–3.675 MJ] [e.c.f.](1) $[-]3.7\text{ MJ} = [-]\frac{GMm}{r}$ (1) $r\left[=\frac{GMm}{3.7\times10^{6}}\right]$ = 2.67 × 10^6 m [or by impl.](1) height = 0.93 ×10^6 m (1) [Errors from mistake over signs → –1; 0.60 × 10^6 m arising from use of mgh scores 1 only]	4 **[11]**
6	*(a)*		$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$ (**subs**)(1) [or by impl.] = 2.33 × 10^{-7} N (1)	2
	(b)	(i)	Arrows drawn from **P** directed away from the 2 +3.6 nC charges	1
		(ii)	[Vertically] up[wards] **or** correct double arrow shown [e.c.f.]	1
		(iii)	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$ (**subs**)(1) [or by impl.] = 129.5 V m^{-1} (1) $E_{Total} = \sqrt{129.5^2 + 129.5^2}$ **or** 2 × 130 sin 45° / cos 45° (1) [freestanding, i.e. $E_{Tot} = E_{indiv} \times \sqrt{2}$ gets 3rd mark] = 183.1 V m^{-1} / N C^{-1} ((**unit**)) (1) [91.6 V loses only 1 mark]	4
	(c)		Potential energy = $\frac{Qq}{4\pi\varepsilon_0 r}$ **or** $V = \frac{Q}{4\pi\varepsilon_0 r}$ (**subs**)(1) attempt at adding both PEs or potentials as scalars (1) Work done = 1.295 × 10^{-7} J (1) [0.65 × 10^{-7} J loses only 1 mark]	3 **[11]**

Question			Marking details	Marks Available
7			Objects [seem to] travel too fast at large distances from centre (1) **Either**: As orbital speed $\propto \sqrt{m}$ (*m* = enclosed mass) [accept *v* increases as *m* increases] (1) this suggests that the galaxy has extra [or hidden] mass (1). Extra mass related to dark matter. **Or**: Far from centre, the mass within the orbit should be ~ constant (1) so orbital speed *v* should be $\propto \frac{1}{\sqrt{r}}$ (theoretical) (1) So enclosed mass $\propto \sqrt{r}$ for constant *v* (1) **Alt**: Observed speeds too large [for objects to remain in galaxy] (1) …so equation shows *M* is 'too large' (1) Speed doesn't fall off [at large distance] as theory suggests so mass extends beyond visible galaxy (1) Extra mass attributed to dark matter (1)	4 **[4]**

Question			Marking details	Marks Available
8	*(a)*		Reasonable orbit of star and companion in mutual orbit shown with Earth shown or direction towards Earth (1). Star orbits the centre of mass[accept ‘common point’] [of the binary system] (1)  Sensible comment relating radial velocity and position in diagram (1)[e.g. – in position shown – red shift – longer wavelength; ½ orbit later – towards Earth so blue shift]	3
	(b)	(i)	1700 [± 50] m s^{-1}	1
		(ii)	$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ (1) (**subs** v and c)[or by impl.] $\Delta\lambda \left[= \frac{1700[\text{ecf}] \times 600 \times 10^{-9}}{3 \times 10^{8}} \right] = 3.4 \times 10^{-12}$ m (1) [No penalty for subsequent addition of $\Delta\lambda$ to λ]	2
	(c)	(i)	170 [± 2] days	1
		(ii)	$v = \frac{2\pi r}{T}$ [**or** $v = \omega r$ **and** $\omega = \frac{2\pi}{T}$] (1) $r = \frac{1700 \times 170 \times 24 \times 60 \times 60}{2\pi}$ [e.c.f.][= 3.97 × 10^{9}]m (1)	2
	(d)		$T = 2\pi\sqrt{\frac{d^3}{G(m_1 + m_2)}}$ (**subs**)(1) $d = \sqrt[3]{\frac{T^2 GM}{4\pi^2}} = 6.63 \times 10^{10}$ m (1)	2
			Either $r_1 = \frac{m_1}{m_1 + m_2} d$ (**subs**)(1) $m_2 = \frac{m_1 r_1}{d - r_1} = 5.1 \times 10^{28}$ kg (1) **Or** $m_1 r_1 = m_2 r_2$ (1) $m_2 \approx \frac{m_1 r_1}{d}$ since $d \approx r_2$ $m_2 = 4.8 \times 10^{28}$ kg (1) [or 4.4×10^{28} kg if 7×10^{10} m used]	2 **[13]**

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