Question	Answer	Marks
2(a)	work done per unit mass	B1
	(work done in) moving mass from infinity	B1
2(b)(i)	(gravitational) fields from the Earth and Moon are in opposite directions	B1
	(resultant is zero where gravitational) fields are equal (in magnitude)	B1
2(b)(ii)	$g \propto M / r^2$	C1
	$5.98 \times 10^{24} / x^2 = 7.35 \times 10^{22} / (3.84 \times 10^8 - x)^2$ leading to $x = 3.5 \times 10^8$ (m)	A1
2(b)(iii)	ϕ (Earth) = $(-)6.67 \times 10^{-11} \times (5.98 \times 10^{24} / 3.5 \times 10^8)$ **and** ϕ (Moon) = $(-)6.67 \times 10^{-11} \times (7.35 \times 10^{22} / 0.38 \times 10^8)$	C1
	$\phi = (-)6.67 \times 10^{-11} \times [(5.98 \times 10^{24} / 3.5 \times 10^8) + (7.35 \times 10^{22} / 0.38 \times 10^8)]$	C1
	$= -1.3 \times 10^6$ J kg^{-1}	A1

Question	Answer	Marks
3(a)	(thermal) energy per unit mass (to cause temperature change)	**B1**
	(thermal) energy per unit <u>change</u> in temperature	**B1**
3(b)(i)	(T =) pV / Nk	**B1**
3(b)(ii)	(pV =) $NkT = ⅓Nm<c^2>$ **or** $pV = NkT$ **and** $pV = ⅓Nm<c^2>$	**M1**
	leading to $½m<c^2> = (3/2)kT$ and $½m<c^2> = E_K$	**A1**
3(b)(iii)	internal energy = ΣE_K (of molecules) + ΣE_P (of molecules) **or** no forces between molecules	**B1**
	potential energy of molecules is zero	**B1**
3(c)(i)	increase in internal energy = Q + work done	**B1**
	constant volume so no work done	**B1**
3(c)(ii)	$c = Q / Nm\Delta T$	**C1**
	$= [N \times (3/2)k\Delta T] / (Nm\Delta T) = 3k / 2m$	**A1**
3(d)	(as it expands) gas does work (against the atmosphere/external pressure)	**B1**
	for same temperature rise) more (thermal) energy needed, so larger specific heat capacity	**B1**

Question	Answer	Marks
4(a)(i)	5.0 cm	**A1**
4(a)(ii)	$\omega = 2\pi / T$ **or** $\omega = 2\pi f$ **and** $f = 1 / T$	**C1**
	$\omega = 2\pi / 4.0$ $= 1.6$ rad s^{-1}	**A1**
4(a)(iii)	$v_0 = \omega x_0$	**C1**
	$= 1.57 \times 5.0$ $= 7.9$ cm s^{-1}	**A1**
4(b)	• initial pull was to the right • distance from X to trolley (at equilibrium) is 20 cm • period is 4.0 s • initial motion undamped • motion becomes damped at/from 12 s • damping is light • maximum speed at 1 s, 3 s, etc. / stationary at 2 s, 4 s, etc. *Any three points, 1 mark each*	**B3**
4(c)	sketch: closed loop encircling (20, 0)	**B1**
	minimum *L* shown as 15 cm and maximum *L* shown as 25 cm	**B1**
	minimum *v* shown as –7.9 cm s^{-1} and maximum *v* shown as +7.9 cm s^{-1}	**B1**

Question	Answer	Marks
5(a)	• noise can be removed/signal can be regenerated • extra bits can be added for error-checking • signal can be encrypted (for increased security) • data compression/multiplexing is possible *Any two points, 1 mark each*	**B2**
5(b)(i)	4 ms: 0101 **and** 8 ms: 0100	**B1**
5(b)(ii)	sketch: horizontal line continues to 8 ms, then new horizontal line from 8 ms to 12 ms	**B1**
	level of line after 8 ms is 4 mV	**B1**
5(c)	sketch: series of steps of width 2 ms	**B1**
	step heights at 0, 2, 4, 6, 4, 6 mV *2 marks if all correct, 1 mark if only one incorrect*	**B2**

Question	Answer	Marks
6(a)	$Q = CV$ **and** $E = ½CV^2$	**B1**
6(b)(i)	$C_N = CL / (L – D)$	**B1**
6(b)(ii)	(charge is unchanged by moving the plates so) $Q_N = CV$	**B1**
6(b)(iii)	$V_N = Q_N / C_N$ $= (CV) / [CL / (L – D)]$ $= V(L – D) / L$	**B1**
6(c)	oppositely charged plates attract, so energy stored decreases	**B1**

Question	Answer	Marks
7(a)	• infinite (open-loop) gain • infinite slew rate • infinite input impedance • zero output impedance • infinite bandwidth *Any two points, 1 mark each*	**B2**
7(b)	X: thermistor **and** Y: relay	**B1**
7(c)(i)	(any) difference in voltage at the inputs causes output to saturate (because gain is very large)	**B1**
	saturates positively if $V^+ > V^-$ <u>and</u> saturates negatively if $V^+ < V^-$	**B1**
7(c)(ii)	comparator	**B1**
7(c)(iii)	temperature	**M1**
	above a particular value	**A1**
7(c)(iv)	to adjust the temperature (at which the lamp illuminates/extinguishes)	**B1**

Question	Answer	Marks
8(a)	newton per ampere per metre	M1
	where current/wire is perpendicular to magnetic field	A1
8(b)(i)	$F = BIL\sin\theta$	C1
	$B = 1.0 / (5.0 \times 0.060 \times \sin 50°)$ $= 4.4$ mT	A1
8(b)(ii)	(from Fleming's left-hand rule) force on wire is upwards, so reading decreases	B1
8(b)(iii)	frame will rotate (so that PQ becomes perpendicular to the field)	B1

Question	Answer	Marks
9(a)	constant voltage	M1
	that produces/dissipates same power as (the mean power of) the alternating voltage	A1
9(b)(i)	(maximum) rate of cutting of (magnetic) flux doubles	B1
	(peak and hence) r.m.s. induced e.m.f. doubles	B1
9(b)(ii)	sketch: (sinusoidal) wave of period 10 ms	B1
	peak *E* shown as ± 34 V (*1 mark out of 2 awarded if peak E shown as* ± 17 V *or* ± 24 V)	B2
9(c)	current in the coil results in forces that oppose its rotation **or** current in the resistor dissipates the energy of rotation	B1
	coil stops rotating	B1

Question	Answer	Marks
10(a)(i)	photoelectric effect	**B1**
10(a)(ii)	electron diffraction	**B1**
10(b)(i)	$\lambda = h / p$	**M1**
	h is the Planck constant	**A1**
10(b)(ii)	de Broglie (wavelength)	**B1**
10(c)(i)	$½mv^2 = eV$	**C1**
	$½ \times 9.11 \times 10^{-31} \times v^2 = 1.60 \times 10^{-19} \times 4800$ <u>so</u> $v = 4.1 \times 10^7$ m s^{-1}	**A1**
10(c)(ii)	$\lambda = h / mv$ $= 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 4.1 \times 10^7)$	**C1**
	$= 1.8 \times 10^{-11}$ m	**A1**

Question	Answer	Marks
11(a)(i)	ease with which edges can be distinguished	B1
11(a)(ii)	difference in degrees of blackening	B1
11(b)	$I = I_0 \exp(-\mu x)$	C1
	$0.12 = \exp(-\mu \times 2.3)$ $\ln 0.12 = -2.3 \times \mu$	C1
	$\mu = 0.92\ \text{cm}^{-1}$	A1
11(c)	advantage: produces 3-dimensional image	B1
	disadvantage: (much) greater exposure to radiation	B1

Question	Answer	Marks
12(a)	probability of decay (of a nucleus)	M1
	per unit time	A1
12(b)	$A = \lambda N$	C1
	N = mass / (nucleon number × u)	C1
	$2.92 \times 10^9 = (\lambda \times 5.87 \times 10^{-10}) / (131 \times 1.66 \times 10^{-27})$ $\lambda = 1.08 \times 10^{-6}\ \text{s}^{-1}$	A1
12(c)	• sample emits radiation in all directions • some radiation is absorbed by air/detector window • self-absorption within the source • dead time/inefficiency of detector *Any two points, 1 mark each*	B2