Astro and Cosmology MS

1. A

[1]

2. C

[1]

3. D

[1]

4. C

[1]

5. C

[1]

6. B

[1]

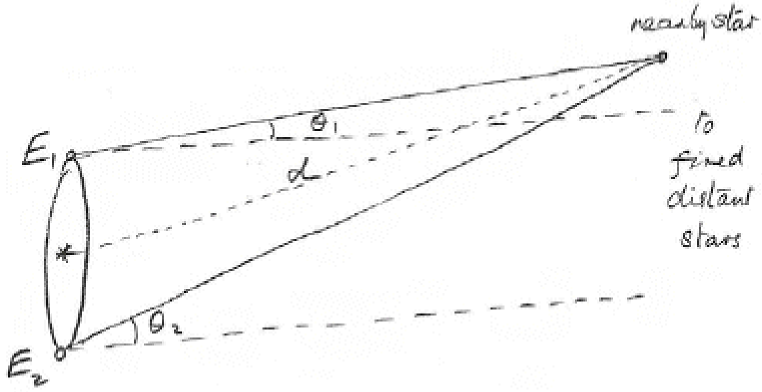
7. (a) Idea that the Earth is orbiting the Sun **(1)**

Reference to (trigonometric) parallax **(1)**

Idea that more distant stars have "fixed" positions **(1)** 3

(b) Diagram to show how to measure angular displacement of star over a 6 month period

e.g.



(1)

[Diagram should indicate the Earth in two positions at opposite ends of a diameter, with lines drawn heading towards a point with a relevant angle marked; accept the symmetrical diagram seen in many textbooks.]

Use trigonometry to calculate the distance to the star **(1)**

[May be indicated by an appropriate trigonometric formula. Do not accept use of Pythagoras]

Need to know the diameter/radius of the Earth's orbit about the Sun **(1)**

[This may be marked on the diagram or seen in a trigonometric formula] 3

(c) Standard candle/Cepheid variable/supernovae **(1)** 1

[7]

8. (a) (i) Use of $\lambda_{max}T=2.898 \times 10^{-3}$ **(1)**

Correct answer **(1)** 2

Example of calculation:

$$T = \frac{2.898 \times 10^{-3}\ \text{mK}}{5.2 \times 10^{-7}\ \text{m}} = 5570\text{K}$$

(ii) Use of $F=L/4\pi d^2$ **(1)**

Correct answer **(1)** 2

Example of calculation:

$$L = 1370\ \text{Wm}^{-2} \times 4\pi \times (1.49 \times 10^{11}\text{m})^2 = 3.8 \times 10^{26}\ \text{W}$$

(iii) Use of $L = 4\pi r^2 \sigma T^4$ **(1)**

Correct answer (7.46×10^8 m) **(1)** 2

Example of calculation:

$$r^2 = \frac{3.82\times10^{26}\ \text{W}}{4\pi\times5.67\times10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}\times(5570\text{K})^4} = 5.57\times10^{17}\ \text{m}^2$$

$$r = \sqrt{5.57\times10^{17}\ \text{m}^2} = 7.46\times10^8\ \text{m}$$

	3.8×10^{-26} W	**4×10^{26} W**
5570 K	7.46	7.6
6000 K	6.4	6.6

(b) The answer must be clear, use an appropriate style and be organised in a logical sequence

QWC

High temperature AND high density/pressure **(1)**
Any **two** reasons from:
- Overcome coulomb/electrostatic repulsion **(1)**
- Nuclei come close enough to fuse/for strong (nuclear) force to act **(1)**
- High collision rate/collision rate is sufficient **(1)** Max 3

[9]

9. (a) (i) Calculation of time period **(1)**

Use of $v = \frac{\Delta s}{\Delta t}$ *or* $\omega = \frac{2\pi}{T}$ **(1)**

Use of $a = \frac{v^2}{r}$ *or* $a = r\omega^2$ **(1)**

Correct answer **(1)** 4

Example of calculation:

$T = \dfrac{25 \times 60 \times 60s}{15} = 5760s$

$v = \dfrac{2\pi r}{T} = \dfrac{2\pi \times 6.94 \times 10^6 m}{5760s} = 7.57 \times 10^3\ ms^{-1}$

$a = \dfrac{v^2}{r} = \dfrac{(7.6 \times 10^3 ms^{-1})^2}{6.94 \times 10^6 m} = 8.26 ms^{-2}$

OR

$\omega = \dfrac{2\pi}{T} = \dfrac{2\pi}{5760s} = 1.09 \times 10^{-3}\ ms^{-1}$

$a = r\omega^2 = 6.94 \times 10^6 \times (1.09 \times 10^{-3})^2 = 8.26\ ms^{-2}$

(ii) mg equated to gravitational force expression **(1)**

g (= a) = 8.3 ms^{-2} substituted **(1)**

Correct answer **(1)** 3

Example of calculation:

$mg = \dfrac{GMm}{r^2}$

$\therefore 8.3ms^{-2} = \dfrac{6.67 \times 10^{-11}\ Nm^2\ kg^{-2}\ M}{\left(6.94 \times 10^6 m\right)^2}$

$\therefore M = \dfrac{8.3ms^{-1} \times \left(6.94 \times 10^6 m\right)^2}{6.67 \times 10^{-11}\ Nm^2\ kg^{-2}} = 6.0\ 10^{24}$ kg

(b) The observed wavelength is longer than the actual wavelength / the wavelength is stretched out **(1)**

One from:

- The universe is expanding **(1)**
- (All distant) galaxies are moving apart **(1)**
- The (recessional) velocity of galaxies is proportional to distance **(1)**
- The furthest out galaxies move fastest **(1)** Max 2

(c) (i) A light year is the distance travelled (in a vacuum) in 1 year by light / em-radiation **(1)**

The idea that light has only been able to travel to us for a time equal to the age of the universe. **(1)** 2

(ii) (Use of v = Ho d to show) $H_o = \frac{1}{t}$ **(1)**

Correct answer **(1)** 2

Example of calculation:

$$H_o = \frac{1}{t} = \frac{1}{12 \times 3.15 \times 10^{16}\,s} = 2.65 \times 10^{-18}\,s^{-1}$$

(iii) The answer must be clear and be organised in a logical sequence

There is considerable uncertainty in the value of the Hubble constant **(1)**

QWC

Any sensible reason for uncertainty **(1)**

Idea that a guess implies a value obtained with little supporting evidence
OR the errors are so large that our value is little better than a guess **(1)** 3

[16]

10. B

[1]

11. C

[1]

12. A

[1]

13. B

[1]

14. D

[1]

15. C

[1]

16. reason **(1)**
and consequence**(1)**
reason **(1)**
and consequence**(1)**

2 from:
Could be different sizes; So larger one could be further away
Could be different temperatures; So hotter one could be further away
Different luminosities; So more luminous one could be further away 4

[4]

17. (a) attempt to find gradient eg evidence of triangle on graph or values of dy/dx **(1)**
value of n **(1)** 2

(b) needs T^4 **(1)**
(electrical) power P related to luminosity **(1)** 2

[4]

18. (a) difficult to measure distances to "far" objects accurately / difficult to measure speeds of far objects accurately **(1)** 1

(b) appreciate 1/H is age of universe **(1)** 1

(c) fate of universe depends on the density of the universe **(1)**
link between gravity and density **(1)**
Hubble "constant" is changing due to gravitational forces **(1)** 3

[5]

19. (a) equates $F = GMm/r^2$ and mv^2/r **(1)**
Use of $v = 2\pi r/T$ **(1)**
Cancel m's To give $GMT^2 = 4\pi^2 r^3$ in any form **(1)** 3

(b) (i) remove constants or cancel G $4\pi 2$ **(1)**
use of idea MT^2 / r^3 = Constant **(1)**
substitution 27 /36 = Mstar / Msun **(1)** 3

(ii) both will complete orbit in same time period **(1)**
star covers small distance / orbit radius smaller compared to planet **(1)** 2

(c) The answer must be clear, use an appropriate style and be organised in a logical sequence **(QWC)**
Larger planets will move centre of mass towards planet / away from star centre **(1)**
Star moves faster **(1)**
Doppler shift greater for larger speeds **(1)** 3

[11]

20. (a) top row : 17 1 (14) 4 **(1)**
bottom row: 8 1 7 2 **(1)**
other product – helium **(1)** 3

(b) The answer must be clear, use an appropriate style and be organised in a logical sequence **(QWC)**
dead star / no longer any fusion **(1)**
small dense hot / still emitting radiation/light **(1)**
consisting of products of fusion such as carbon / oxygen / nitrogen **(1)** 3

(c) (i) use of 3/2 kT **(1)**
conversion to eV **(1)**
answer [1.3 (keV)] **(1)** 3

(ii) gravitational force does work on hydrogen **(1)**
increases internal energy of gas **(1)** 2

(d) The answer must be clear, use an appropriate style and be organised in a logical sequence **(QWC)**
A standard candle (in astronomical terms) produces a fixed amount of light /luminosity **(1)**
Quantity of hydrogen **(1)**
and fusion temperature **(1)** must be similar for various novae. 3

[14]

21. **Core remnant stars**

All core remnants ticked AND no main sequence **(1)**

$< 1.4\ M_\odot$ column: White dwarf only **(1)**

$> 2.5\ M_\odot$ column: Black hole only **(1)** 3

[3]

22. (i) **Hydrogen burning**

Quality of written communication **(1)**

Nuclear fusion reaction [accept nuclei, nucleus, fusing] **(1)**

Hydrogen / deuterium /protons turn into He [penalise contradictions, e.g. molecules atoms; accept symbols] **(1)**

Release of energy **(1)** 4

(ii) **Sun as red giant calculation**

Attempted use of $L = \sigma T^4 A$ (accept r substituted as A) **(1)**

$A = 4\pi r^2$ [or $A \propto r^2$ if ratios calculated directly] **(1)**

3.85×10^{26} (W) or 1.13×10^{30} (W) [or substitution as ratio] **(1)**

2930 [accept 2900 – 2940] **(1)**

$L = \sigma T^4 A = 4\pi\sigma T^4 r^2$
$L_{before} = 4\pi \times 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^4 \times (5780\ \text{K})^4 \times (6.96 \times 10^8\ \text{m})^2$
$= 3.85 \times 10^{26}\ \text{W}$
$L_{after} = 4\pi \times 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^4 \times (3160\ \text{K})4 \times (1.26 \times 10^{11}\ \text{m})^2$
$= 1.13 \times 10^{30}\ \text{W}$
Hence ratio $= 1.13 \times 10^{30}\ \text{W} \div 3.85 \times 10^{26}\ \text{W} = 2930$ 4

(iii) **H-R diagram plots**

X at 10^0 on main sequence [± 1 mm by eye] AND between 5000 K and centre of 5000 – 10 000 K box **(1)**

Y above and to right of actual $X_\odot$ **(1)**

Attempt to plot Y at 3160 K [between 5000 K and 2500 K] **(1)**

Attempt to plot Y between $10^3\ L_\odot$ and $10^4\ L_\odot$ [ecf] **(1)** 4

[12]

23. (i) **Sun as white dwarf**

Any 2 [comparative statements] of

Higher temperature / hotter
Lower luminosity [accept Power, not E or I]
No fusion in core [or equivalent; not just "not on main sequence"]
More dense **(1)** + **(1)** 2

(ii) **Future of white dwarf**

Cools / T decreases **(1)**

Dims / fades / correct colour change [not brown dwarf] / Luminosity decreases [accept intensity here] **(1)** 2

[4]

24. (i) **Distance to Sirius**

Substitution in $v \times t$ /s [ignore 8.6, accept 365 or 365¼ days] **(1)**

8.1×10^{16} (m) [8.13, 8.14] **(1)**

$d = v\,t$
$= 8.6 \times 3.00 \times 108 \text{ m s}^{-1} \times (60 \times 60 \times 24 \times 365¼) \text{ s}$
$= 8.1 \times 10^{16} \text{ m}$ 2

(ii) **Sirius A intensity calculation**

Use of $I = L / 4\pi D^2$ **(1)**

Correct substitution **(1)**

$1.2 \times 10^{-7} \text{ W m}^{-2}$ [1.20 – 1.24] **(1)**

$I = L / 4\pi D^2$
$= 1.0 \times 10^{28} \text{ W} / 4\pi (8.1 \times 10^{16} \text{ m})^2$
$= 1.2 \times 10^{-7} \text{ W m}^{-2}$ 3

(iii) **Mass rate conversion**

$E = m c^2$ seen [or implied] **(1)**

Correct substitution **(1)**

1.1×10^{11} kg (s^{-1}) **(1)**

$1.0 \times 10^{28} \text{ W} = 1.0 \times 10^{28} \text{ J s}^{-1}$

$\Delta m = \Delta E / c^2$
$= 1.0 \times 10^{28} \text{ J} / (3.00 \times 10^8 \text{ m s}^{-1})^2$
$= 1.1 \times 10^{11} \text{ kg}$ 3

(iv) **Peak wavelength calculation**

Use of Wien's law **(1)**

2.93×10^{-7} m **(1)**

$\lambda_{max} = 2.90 \times 10^{-3}$ m K / 9900 K
$= 2.93 \times 10^{-7}$ m 2

[10]

25. (i) **Binding energy**

Energy required to separate a nucleus into nucleons **(1)** 1

(ii) 8n + 6p **(1)**

Substitution / $m = 0.1098$ u **(1)**

Multiply by 930 [only, or $E = m\,c^2$ route] **(1)**

102 MeV [or 103 MeV] **(1)**

$\Delta m = (6 \times 1.007\,28\text{ u}) + (8 \times 1.008\,67\text{ u}) - 14.003\,24\text{ u} = 0.1098\text{ u}$
$\Delta E = 0.1098\text{ u} \times 930\text{ MeV/u} = 102\text{ MeV}$ 4

(iii) **More stable isotope**

Binding energy per nucleon attempted **(1)**

7.4 (MeV) and 7.3 (MeV) [accept 7.1, ecf] **(1)**

Hence carbon–12 [based on two values, ecf] **(1)**

BE / A (^{14}C) = 102 MeV / 14 = 7.3 MeV
BE / A (^{12}C) = 89 MeV / 12 = 7.4 MeV 3

[8]

26. (a) (i) Line B

Knot T at 2.4 m [±½ small square, no label needed] **(1)**

(ii) Knots Q, R, S at 0.6, 1.2, 1.8 m [±½ small square, no labels needed]
[ecf from wrong position of knot T i.e. Q at ¼T, R at ½T & R at ¾T]**(1)** 2

(b) How model represents the Universe and its behaviour

Knots/letters/points represent <u>galaxies</u> **(1)**

Reference to expansion of Universe / galaxies moving apart
[NOT galaxies move away and stay same distance apart] **(1)** 2

(c) How model illustrates Hubble‾s law

Stating or showing velocities are different for 2 of the knots **(1)**
[Shown by either calculating speeds or comparing distances moved between diagrams A and B]

Calculation of velocity for at least 2 of the knots [other than T] **(1)**

Use of their data to show speed (of knot) $\propto$ distance (from P) **(1)**
Examples:
determine values of $v \div d$ [allow $v \div \Delta d$]
sketch graph of v against d [allow v against Δd] 3

(d) Defects of the model

Any 2 sensible points **(1)(1)**

Examples:
Galaxies are not evenly spaced
Initial spacing of knots is not zero
No force pulling galaxies/Universe apart
Rate of expansion of Universe OR speed of galaxies increasing/ not constant [not speed decreasing]
Relative sizes of knot and spacing are unrealistic
Universe is 3 dimensional/galaxies are not in a straight line 2

[9]

27. (a) (i) GM_S/R^2 (*)

(ii) GM_E/r^2 (*) **(1)** 1

(*) (*symbols* ***must*** *be as given in the Q*, though allow lower case m)

(b) (i) Evidence of equating of GM_S/R^2 and GM_E/r^2 (ecf from part a) **(1)**

Correct answer 570 – 580 **(1)**

Example of answer:

$$\frac{GM_S}{R^2} = \frac{GM_E}{r^2} \rightarrow \frac{M_S}{R^2} = \frac{M_E}{r^2} \rightarrow \frac{R^2}{r^2} = \frac{M_S}{M_E}$$

$$\therefore \frac{R}{r} = \sqrt{\frac{M_S}{M_E}} = \sqrt{\frac{2.0\times10^{23}\text{ kg}}{6.0\times10^{24}\text{ kg}}} = \sqrt{3.33\times10^5} = 577$$ 2

(ii) 1.5×10^8 km × 1/601 [ignore powers of 10 in distance value] **(1)**

Correct answer 2.5 – 2.6 × 10^5 km (or 2.5 – 2.6 × 10^8 m) **(1)** 2

(c) Letter L on or against line to left of point P (coming within one Earth radius of dotted line) **(1)**

Reason*:
[*Consequent marks; allow **only** if L position correct or not shown]

Reference to centripetal force/centripetal acceleration/ (net) force towards Sun **(1)**

Force due to Sun must be > force due to Earth **(1)** 3

[8]

28. (a) Name of reaction

- (Nuclear) fusion 1

(b) (i) How to determine distance of star

- Explanation using $F = L / 4 \pi d^2$ (Use known luminosity with measured flux at Earth to determine d) 1

(ii) How to determine velocity of star

- Mention of Doppler Effect OR red shift
- Identify (pattern of) lines and **compare with** lab frequency
- $\Delta f \propto$ (relative) v OR the greater the velocity of the star (relative to Earth), the greater the change in frequency/wavelength observed Max 2

(c) (i) Line of best fit

- Insertion of line of best fit, through origin ± 1 square, with approx. the same number of points each side of line
- Idea that the greater the distance to the galaxy, the greater its velocity (relative to Earth) 2

(ii) Use of gradient to calculate age of universe

- Use of $v = H_o d$ to argue that Ho is the gradient of the graph
- Correct answer for age of universe

[4.6×10^{17} s, accept 4.0×10^{17} s → 5.2×10^{17} s]

Example of calculation:
1/gradient = 120×10^6 pc × 3.09×10^{16} m pc^{-1}/ $8{,}000 \times 10^3$ m s^{-1} =
4.6×10^{17} s 2

[8]

29. (a) (i) Meaning of symbols

- m = mass of a gas molecule
- $<c^2>$ = mean square speed of gas molecule
- T = absolute temperature [accept kelvin temperature] 3

(ii) Physical quantity represented

- (mean) kinetic energy (of a gas molecule) 1

(iii) Calculation of velocity

- Use of $\frac{1}{2} m < c^2 > = 3/2\, k\, T$ with T = 223 K
- Correct answer for velocity [410 m s^{-1}]

Example of calculation:

$c = \sqrt{(3 \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 223 \text{ K} / 5.4 \times 10^{-26} \text{ kg})} = 413 \text{ m s}^{-1}$ 2

(b) (i) Obtain expression for escape velocity

- Idea that total energy must be zero for molecule just to escape
- So, $\frac{1}{2} m\, v_{esc}^2 - GMm/r = 0$, leading to required equation 2

(ii) Show that escape velocity > 10 km s^{-1}

- Use of $vesc = \sqrt{(2GM/r)}$ with r = (6.37 + 0.01) × 10^6 m
- Correct answer for escape velocity [11.1 km s^{-1}, at least 2 sig. figs. required]

Example of calculation:

$v_{esc} = \sqrt{(2GM/r)}$

$v_{esc} = \sqrt{(2 \times 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 5.98 \times 10^{24} \text{ kg} /(6.37 + 0.10) \times 10^6 \text{ m})}$

$= 1.11 \times 10^4 \text{ (m s}^{-1})$

$= 11.1 \text{ (km s}^{-1})$ 2

(iii) Use of graph to explain whether molecules are likely to escape

- Idea that only a tiny fraction of molecules have a very high velocity
- Any quantitative attempt to compare the r.m.s. velocity with the escape velocity leading to the conclusion that molecules are not likely to escape. e.g. 410 is much less than 11,000 2

[12]

30. (i) Sun now & as red giant

Similarity: (nuclear) fusion / burning (in core) OR mass **(1)**

Difference: H vs. He fusion / r.g. lower (surface) *T*/ r.g. higher core T / r.g. lower (mean) density [assume r.g. referred to **if** not specified] **(1)**

(ii) <u>White Dwarf star terms</u>

Hot, low, (surface) area, off (the main sequence)

Any three correct **(1)**

All four correct **(1)** 4

[4]

31. (i) <u>Large mass star fusion rate</u>

Quality of written communication **(1)**

(30 $M_\odot$ star) fuses at a greater rate AND spends less time on m.s. **(1)**
[accept power, luminosity]

(30 $M_\odot$ star) has greater temperature / (gravitational) forces / pressure **(1)**

leaves main sequence after <u>hydrogen</u> (and/or He) burning ceases / <u>H</u> fuel depleted (in core) [accept H "used up"] **(1)** 4

(ii) <u>2.2 $M_\odot$ core remnant</u>

Neutron star (1) 1

(iii) <u>Sun evolutionary phases</u>

Red giant (1)

White dwarf (1)

Black dwarf (1)

[–1 mark per error only if more than three phases circled] 3

[8]

32. (a) <u>Calculation of recession speed</u>
$\lambda = 684 - 656$ **(1)**
Use of $v/c \quad \lambda/\lambda$ **(1)**
1.28×10^7 m s^{-1} **(1)**

[Substituting 684 for λ, leading to 1.23×10^7, loses last two marks] 3

$(3.00 \times 10^8 \text{ m s}^{-1})(28 \times 10^{-9} \text{ m})/(656 \times 10^{-9} \text{ m})$
$= 1.28 \times 10^7$ m s^{-1}

(b) Calculation of wavelength received from Y
By Hubble's law / $v = Hd$ / v proportional to d, as d is doubled,
v is doubled **(1)**
λ = 56 / is doubled **(1)**
712 nm **(1)**

[Bald answer of 712 nm, with no working or explanation, gets 2 marks only]

[If candidate gets part (a) wrong, accept EITHER 56, 712 for the last two marks (if they have avoided reusing the formula or made the same mistake again) OR ecf (if they have repeated the calculation but avoided the original mistake)] 3

[6]

33. (a) Two deductions [not simplv word descriptions of features of the diagram]

The gravitational potential is increasing with height / when moving away from the Earth / Work must be done to move away from the Earth **(1)**

[Ignore idea that $V \propto \frac{1}{r}$; in words or symbols]

The field is non-uniform / radial / Field strength decreases with height / when moving away from the Earth **(1)** 2

(b) Entry speed at Earth's atmosphere

| $-1\text{MJkg}^{-1} - (-61\text{MJkg}^{-1}) = 60\text{MJkg}^{-1}$ [accept $\pm 60\text{MJkg}^{-1}$] **(1)**

Loss of GPE/ Gain in KE of spacecraft = m **(1)**

Statement / use of $\frac{1}{2} mv^2 = m\Delta V$ OR $\frac{1}{2}v^2 = \Delta V$/(= 60 MJ kg^{-1}) **(1)**
[either of these statements also earns the second mark, if not already awarded]
[See $v^2 = 1.2 \times 10^8$

Answer 1.095 × 103 m s^{-1} /10950 m s^{-1}/11.0 km s^{-1} [more than 2 sf] **(1)** 4

(c) Showing relative distance

Use of Newton's Law; FE = $\dfrac{GM_E m}{r_E^{\,2}}$ or FM = $\dfrac{GM_M m}{r_M^{\,2}}$ **(1)**

$\dfrac{r_E^{\,2}}{r_M^{\,2}} = \dfrac{M_E}{M_M}$ (or) $\dfrac{r_E}{r_M} = \dfrac{\sqrt{M_E}}{\sqrt{\mathrm{M}_M}}$ **(1)**

[or equivalent re-arrangement]

$\dfrac{r_E^{\,2}}{r_M^{\,2}} = \dfrac{6.0\times10^{24}\ \mathrm{kg}}{7.4\times10^{22}\ \mathrm{kg}} = 81(.1)$ [or equivalent] **(1)**

[correct relationship, expressed in terms of numerical values]
[If inverted, then MM:ME = 0.0123]

So $\dfrac{r_E}{r_M} = \sqrt{81} = 9$ [or $\dfrac{r_M}{r_E} = 0.11$] (independent mark) **(1)**

[Stating 81 =100 at the third mark stage does not, alone, earn the 4th mark]

[Beware ambiguity or transposition of r values at steps 2 or 3] 4

[10]

34. (a) Intensity and Luminosity

Luminosity = power [or energy / time, accept "per second"] **(1)**

Intensity = power (or energy / time) [e.c.f. from first mark] per unit area [accept per square metre] **(1)**

Luminosity: measured at star OR Intensity: measured at Earth / depends on distance (from star) / observed OR W with W m^{-2} OR $I = L \div 4\,\pi\,D^2$ **(1)** 3

(b) (i) Wavelength of Sun

Use of Wien's law [accept any attempted use] **(1)**

5.0×10^{-7} m **(1)** 2

(ii) Surface area of Sun

Use of $4\,\pi\,r^2$ **(1)**□

6.1×10^{18} (m^2) **(1)** 2

(iii) Luminosity of Sun

$L = \sigma A T^4$ [or $L = \sigma T^4 4 \pi r^2$] **(1)**

Correct substitution [e.c.f.] **(1)**

3.9×10^{26} W [accept 3.8 or 3.84×10^{26} W from 6×10^{18} m^2] **(1)**□ 3

[10]

35. (a) Main sequence mass requirement

Quality of written communication **(1)**

(Main sequence requires) hydrogen fusion / burning **(1)**

Mass linked to gravitational forces / field [/energy] **(1)**

High forces [or temperature, pressure] required for fusion / burning / m.s. **(1)** 4

(b) Hertzsprung-Russell diagram

(i) Axes change in (fixed) multiples [accept exponential changes] **(1)**

x-axis multiple: × ½ OR × 2 **(1)** 2

(ii) L on diagonal falling line in lower right quadrant **(1)**

W indicated mostly in lower left quadrant **(1)**

R indicated mostly in upper right quadrant [not on main sequence] **(1)**

S in line with 10° [± 2 mm to centre of S, to left of 5000 K. on m.s.] **(1)** 4

[10]

36. Parallax analogy

(i) 5 tan 84° [beware 5 / cos 84° = 47.8 m] **(1)**

47.6 m **(1)** 2

(ii) 2 AU / Earth orbital radius × 2 / Earth orbital diameter / distance between Earth at a six month interval / 3×10^{11} m **(1)** 1

(iii) Inaccurate readings / difficult to measure AND small angles / movement relative to background (stars) **(1)** 1

[4]

37. (a) Show that

See ‘v = $\frac{2\pi r}{T}$ ’ OR ‘$\omega = \frac{2\pi r}{T}$ ’ **(1)**

Substitution of (60 × 60 × 24)s or 86400s for T (giving 7.27 × 10^{-5}, no u.e.) **(1)**

Unit of ω

s^{-1}/rad s^{-1} **(1)** 3

(b) Height above Earth’s surface

Statement / use of $\frac{GM_E m}{r^2} = \frac{mv^2}{r}$ OR $\frac{GM_E m}{r^2} = mr\omega^2$ **(1)**

[Equations may be given in terms of accelerations rather than forces]
[Third mark (from below) may also be awarded here if ($r_E + h$) is used for r]

Correct value for r, i.e. 4.2(3) × 10^7 m **(1)**
Use of h = their $r - R_E$ **(1)**

Correct answer = (3.58 – 3.60) ×10^7 m [no ecf] **(1)**

Example of answer:

$$\frac{GM_E m}{r^2} = \frac{mv^2}{r}$$

$$\rightarrow \frac{GM_E}{r^2} = \frac{v^2}{r} = \frac{(\omega r)^2}{r} = \omega^2 r$$

$$\therefore GM_E = \omega^2 r^3$$

$$\therefore r = \sqrt[3]{GM_E / \omega^2} = \sqrt[3]{\frac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 5.98 \times 10^{24}\ \text{kg}}{(7.27 \times 10^{-5}\ \text{s}^{-1})^2}}$$

= 4.23 × 10^7 m

$\therefore$ h = 4.23 × 10^7 m – 6.38 × 10^6 m

= 3.59 × 10^7 m 4

[7]

38. (a) Expression for gravitational force:
$F = GMm/r^2$ **(1)** 1

(b) Expression for gravitational field strength:
g = force on 1 kg, so $g = GM/r^2$, or g = F/m so $g = GM/r^2$ 1

(c) Radius of geostationary orbit:
Idea that a = g, **and** suitable expression for a quoted [can be in terms of forces] **(1)**
substitution for velocity in terms of T **(1)**
algebra to obtain required result **(1)** 3

Example of derivation:
$g = v^2/r$ **or** $g = \omega^2 r$
and $v = 2\pi r/T$ ***or*** $\omega = 2\pi/T$
so $(2\pi r/T)^2/r = GM/r^2$ **or** $(2\pi/T)^2 r = GM/r^2$, leading to expression given

(d) Calculation of radius:
Substitution into expression given **(1)**
Correct answer [4.2×10^7 m] **(1)** 2

Example of calculation:
$r^3 = 6.67 \times 10^{-11}$ N m^2 kg^{-2} $\times 6.0 \times 10^{24}$ kg $\times (24 \times 60 \times 60\ \text{s})^2 / 4\pi^2$
$= 7.6 \times 10^{22}$ m^3
So $r = 4.2 \times 10^7$ m

(e) (i) Satellite with greater mass:
Yes – because, in geostationary orbit, r constant so acceleration remains the same, regardless of mass **(1)**

(ii) Satellite with greater speed:
No + suitable argument **(1)** 2
[e.g. for geostationary orbit, T and r are fixed, so v cannot increase ($v = 2\pi r/T$)]

(f) Why satellite must be over equator:
Idea that centre of satellite's orbit must be the centre of the Earth (can be shown on diagram) **(1)**
there must be a common axis of rotation for the satellite and the Earth / the satellite's orbit must be at right angles to the spin axis of the Earth **(1)** 2

[11]

39. (a) Description of fusion:
Two light nuclei combine to form a single (heavier) nucleus **(1)**
Energy is released **(1)** 2

(b) Need high temperature **and** high density / pressure **(1)**

and one point from:

- to overcome electrostatic repulsion / for a large collision rate
- a reference to containment problems **(1)** 2

(c) When hydrogen nuclei fuse, there is a loss of mass
This is converted into energy, according to: $\Delta E = c^2 \Delta m$ 2

[6]

40. (a) Wien's law

(i)
- Wavelength of peak [or maximum] intensity [allow brightness, but not power / energy / L] **(1)**
- Absolute or Kelvin (surface) temperature (of star) **(1)** 2

Spectrum

(ii) Microwave / infra–red [accept i.r.] **(1)** 1

(iii) λ_{max} = 1.05 (mm) **(1)**

Substitution in $T = 2.90 \times 10^{-3}$ m K ÷ their λ_{max} with $\times 10^{-3}$ **(1)**
[2.90×10^{-3} m K ÷ 1.05×10^{-3} m, with mm → m conversion required]

T = 2.76 [accept range 2.6 – 2.9] K **(1)** 3

(b) (i) Supernova minimum mass

$8\ M_{\odot}$ [accept 1.6×10^{31} kg] **(1)** 1

(ii) Energy from Sun

$1 \times 10^{10} \times 365(¼) \times 24 \times 60 \times 60 / 3(.15) \times 10^{17}$ **(1)**

Use of $E = P \times t$ **(1)**

$1(.2) \times 10^{44}$ J [Beware $E = \frac{P}{t} \Rightarrow 1.24 \times 10^{9}$ J] **(1)**

$E = P \times t$
$= 3.9 \times 10^{26}$ W $\times 1 \times 10^{10} \times 365(¼) \times 24 \times 60 \times 60$ s
= 1.2 × 1044 J 3

(iii) $10^{46} \div (1.2 \times)\ 10^{44}$ [ecf for any E] **(1)**

80 – 100 [ecf] [accept 83:1 or 1:0.012] **(1)**
[inverted answer scores zero, unless values identified for 1/2] 2

(iv) Supernova future

neutron star / pulsar **(1)**

black hole **(1)**

n.s. if > 1.4 $M_\odot$ OR b.h. if > 2.5 $M_\odot$ **(1)** 3

(c) Neutron star density

(i) $\rho = m \div V$ and $4/3\ \pi\ r^3$ **(1)**

4.2 [or 4.3] $\times 10^{17}$ (kg m^{-3}) **(1)**

$\rho = m \div V$
$= 3m \div 4\ \pi\ r^3$
$= 3 \times 6.0 \times 10^{24}$ kg $\div (4\ \pi\ (150\ \text{m})^3)$
$= 4.2 \times 10^{17}$ kg m^{-3} 2

(ii) Neutron formation

Quality of written communication **(1)**

Main sequence: fusion (reaction) / (ms) p → n / beta plus decay **(1)**

[post ms] p + e^- → n **(1)**

[post ms] due to gravitational collapse / implosion **(1)** 4

(d) Intensity of Sun

(i) Use of $I = L \div (4\pi\ D^2)$ **(1)**

597 OR 1380 (ignore 10^n) **(1)**

597 W m^{-2} AND 1380 W m^{-2} [accept W km^{-2} with appropriate values] **(1)** 3

$I = L \div (4\pi\ ^{D2)}$
$I_M = 3.90 \times 10^{28}$ W $\div (4\pi\ (2.28 \times 10^{11}\ \text{m})^2)$
$= 597$ W m^2
$I_E = 3.90 \times 10^{28}$ W $\div (4\pi\ (1.50 \times 10^{11}\ \text{m})^2)$
$= 1380$ W m^{-2}

$597 \div 1380$ [ecf, accept $(2.28 \div 1.50)^2$] **(1)**

43% **(1)** 2

[26]

41. H–R Diagram

(i) L and T ***(1)***
$L_{\odot}$ and K **(1)** 2

or L and $L_{\odot}$ ***(1)***, T and K **(1)**, not W]

(ii) Any 2 correct [of 10^2, 1 or 10°, 10^{-2}] **(1)**
All 3 correct **(1)** 2

(iii) 20 000 and 5 000 **(1)** 1

Identify stars

(iv) Red giant = (B and) C **(1)**
Low mass ms star = E [ignore X] **(1)** 2

Zeta Tauri Luminosity

(v) Use of $L = 4\,\pi\,D^2\,I$ **(1)**
Correct substitution **(1)**
$3.8(2) \times 10^{30}$(W) **(1)** 3

Zeta Tauri identification (ecf)

(vi) $3.8(2) \times 10^{30}$ W ÷ 3.9×10^{26} W [or 4×10^{30} W used] **(1)**
Correct ratio [e.g. 9700, 9800, 10300 or 10^4, etc.] **(1)**
Hence A [from answer in range 9700 to 10300] **(1)** 3

[13]

42. (i) Fusion calculations
Mass difference substitution [(2 × 5.0055) – (6.6447 + 2 × 1.6726)] **(1)**
2.11×10^{-29} kg [or 0.0211×10^{-27} kg] **(1)** 2

(ii) $E = mc^2$ seen **(1)**
1.9×10^{-12}J[ecf] **(1)** 2

[4]

43. White dwarf density

(i) $M \div \frac{4}{3} \pi r^3$ [allow M, m, R, r] **(1)** 1

(ii) Any pair of values correctly read [may be implied, ignore 10^6] **(1)**
Any correct substitution [with 2.0×10^{30} and 10^6, ecf on (i)] **(1)**
Two correct answers [in kg m^{-3}, no statement required] **(1)** 3

White dwarf future

(iii) Cools / temperature decreases **(1)**
Becomes dimmer / changes colour [not brown dwarf] **(1)** 2

[6]

44. (a) (i) Hubble constant
Use of $v = Hd$ or gradient = H **(1)**
Converts y to s i.e. × (365 × 24 × 60 × 60) **(1)**
Correct × by 'c' **(1)**
[Seeing 9.46×10^{15} gets previous two marks]
1.7 to 1.8×10^{-18} (s^{-1}) **(1)** 4

[No marks for a bald answer]

e.g. $H = 60 \times 10^6$ m s^{-1} /
(3.6×10^7 1y × 365 × 24 × 3600 × 3 × 10^8 m $1y^{-1}$)
= 1.8×10^{-18} s^{-1}

(ii) Uncertainty
Distance / d **(1)** 1

(b) Age of Universe
States that $d = vt$ (any arrangement) **(1)**
Combines this with restated Hubble law (any arrangement) to give
$t = \frac{1}{H}$ **(1)** 2

(c) Recessional Speed
Red shift = 76 nm / 469 – 393 nm **(1)**

Use of $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ **(1)**

5.8×10^7 m s^{-1} **(1)** 3

e.g. $v = 76 \times 10^{-9}$ m × 3 × 10^8 m s^{-1}/393 × 10^{-9} m
= 5.8×10^7 ms^{-1}

(d) Average mass-energy density
Closed : high density/above critical density **(1)**
Then gravitational pull (or force or attraction) sufficient to cause
Big Crunch/pull everything back/stop expansion **(1)**
[NOT to hold the galaxies together]
OR equivalent argument for Open
[Don't accept mass for density in mark 1 or just "gravity" in mark 2] 2

[12]

45. (a) Newton's law

Equation route:

$$F = \frac{GM_1M_2}{R^2} \quad \textbf{(1)}$$

M_1, M_2, R defined correctly, G defined correctly or not defined **(1)**
[Both marks can be awarded for word equation]

OR Proportion route:
(force is directly) proportional to the **product** of the masses
[plural] and

inversely proportional to the square of their separation [not just
'radius', unless related to orbital motion] **(1)** 2

(b) (i) Graph

Take two pairs of values off graph **(1)**

A). Find gR^2 for one pair [$\approx$ 400 ($\times 10^{12}$)]

Attempt to show $gR^2 \approx$ same for second pair **(1)**
(within uncertainty limits of data read from graph) **(1)**

OR B). Compare pairs of values to show that as R changes by a
factor n, g changes by a factor $1/n^2$. **(1) (1)**

OR C). Substitute into formula with one pair to give a value of
M or some other constant. **(1)**

Repeat with second pair to give same value OR substitute back to
confirm agreement of second pair of values. **(1)** 3

(ii) Gravitational field strength
Valid approach via routes A, B or C above. **(1)**
g = 0.0027 – 0.0031 N kg^{-1} **(1)** 2

Example of answer:
$g \times 380^2 = 400 \rightarrow g = 400/\ 380^2 = 0.00277$ N kg^{-1}

(c) Effect
Maintains the Moon in orbit around the Earth / keeps Moon **(1)**
rotating around the Earth / provides (**all** the) centripetal **(1)**
force/acceleration for its circular motion / pulls Moon towards Earth. [**not** just exerts force on the Moon] 1

[8]

46. Doppler effect:
2 points from

- As ambulance approaches, frequency is higher (than normal) **(1)**
- As ambulance recedes, frequency is lower (than normal) **(1)**
- At moment of passing observed frequency = siren frequency **(1)** max 2

Diagram and explanation:

Diagram shows planet, star and Earth in line, with planet on far side of star **(1)**
Diagram shows planet, star and Earth in line, with planet between star and Earth **(1)**
Idea that planet attracts star towards itself **(1)**
Hence star experiences a change in velocity towards planet **(1)**
Max f / min λ / blue shift when planet is nearest Earth **or** min f / max λ / red shift when planet is furthest away from Earth [must be referring to radiation from the **star**] [must not refer to sound] **(1)** max 4
[A good diagram can score all 4 marks. Information on the diagram overrules written]

Time for orbit:
Idea of measuring/identifying the time taken for planet to return to the **same** position in its orbit or half an orbit **(1)** 1
[e.g. the time between successive minima or maxima / the time between the start of red shift and the start of blue shift is half an orbit]

Explanation:
$F = GMm/r^2$ quoted [watch out for F change to g] **(1)**
(For the Earth) m is very small [accept size is very small] **(1)**
Hence the force exerted on the star is smaller(despite a smaller r) **(1)**
Change in velocity / wobble produced is too small to give an observable Doppler shift [frequency shift, red/blue shift accepted in place of Doppler shift] **(1)** 4

[11]

47. Definitions:
An electric field is a region where charged objects experience a force ($E = F/Q$) **(1)** 1
A gravitational field is a region where masses experience a force($g = F/m$) **(1)** 1

Similarities:

- Both fields obey an inverse square law
  OR inverse square equations quoted **(1)**
- Both fields are radial for point objects / spherical distributions **(1)**
- Both fields have an infinite range / field strength approaches
  zero a long way from source **(1)** max 2

Differences:

- Electric forces can be attractive or repulsive but gravitational
  forces are always attractive **(1)**
- Electric forces are (much) stronger than gravitational forces
  OR comparison of size of coupling constants in the two
  force equations **(1)**
- Electric forces only act on charged particles but gravitational
  forces act on all matter **(1)**
- Electric forces can be shielded (e.g. by use of a Faraday
  cage) but gravitational forces cannot **(1)** max 3

[6]

48. <u>Background wavelength</u>

Use of $\lambda_{max}\,T = 2.90 \times 10^{-3}$ m K **(1)**

Correct substitution **(1)**

1.06 (or 1.1) $\times 10^{-3}$m **(1)** 3

<u>Part of spectrum</u>

Microwave or infra-red **(1)** **(1)**

[3]

49. <u>Main sequence star definition</u>

(Fusion of) hydrogen (nuclei) / protons to helium (nuclei) **(1)**

stably / in equilibrium / in core **(1)** 2

<u>Hertzsprung-Russell diagram</u>

Diagonal falling line **(1)**

Correct curvature above 20 000 K **and** below 5000 K **(1)** 2

X on line and level with 10^0 (to ± 1 mm) [must be clearly indicated] **(1)** 1

Dwarfs and Giants

(i) bottom left quadrant **(1)** 1

(ii) top right quadrant **(1)** 1
[no region indicated max. **(1) x**]

T consistent with diagram at centre of region **and** $2500 < T/K < 10000$ **(1)** 3

[10]

50. More MS stars

(i) γ Cas **(1)**

(ii) α Cen B **(1)** 2

Diameter of Sirius A

$26 \times 3.9 \times 10^{26}$ **(1)**

1.0×10^{28} W (ue) **(1)** 2

$L = \sigma T^4 A$ (or implied by substitution) **(1)**

$A = 2.46$ (or 2.43 or 2.45) $\times 10^{19}$ (m^2) **(1)** 2

Use of $\pi d^2/4\pi r^2/1.4 \times 10^9$ m **(1)**

2.8×10^9 m[no ecf] **(1)** 2

[8]

51. (a) Neutron Capture Equation

$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$ **(1) (1)**

Beta minus decay

$^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}\beta + \bar{v}$

U $\rightarrow$ Np + β^- **(1)**

Hence all six numbers correct **(1)**

antineutrino **(1)** 3

(b) (i) Binding energy per nucleon graph

Nucleon number / mass number **(1) (1)**

(ii) Nuclei on graph

H at start of curve (< 3 MeV), Fe at peak of curve (at 56),
U at end of curve (at 235) [to ± 1mm]

any two **(1)**

all three **(1)**

(iii) Fe (ecf) **(1)** 3

(iv) Binding energy of U

7.5/7.6(ecf) **(1)**

× 235 **(1)**

1.8 (GeV) [allow 1.76 – 1.80, no e.c.f] **(1)** 3

[9]

52. (a) Units

s^{-1} / km s^{-1} kpc^{-1} /km s^{-1} Mpc^{-1} **(1)** 1

(b) Estimate

See $d = vt$ or rearrangement **(1)**

Substitution in $v = Hd$ for v to give $t = 1/H$ **(1)**

[Substitute value of H to obtain t]

Assumption

Since the Big Bang/start of time **(1)**

(All) galaxies/galaxy is/are travelling at constant speed /no **(1)**
gravitational attractive forces / Universe expands at a constant rate

[H is constant scores max 1 for Assumption. Allow credit for the 4 marking points anywhere within (b)] 4

[5]

53. Base units of intensity

(i) $W = J\ s^{-1}$ / $N\ m\ s^{-1}$ or $P = E / t$ or $P = F\ v$ **(1)**

$J = kg\ m^2\ s^{-2}$ or $kg\ m\ s^{-2}\ m$ **(1)**

Algebra to $kg\ s^{-3}$ shown (e.g. $kg\ m^2\ s^{-2}\ s^{-1}\ m^{-2}$) **(1)** 3

Luminosity calculation

(ii) Correct substitution **(1)**
3.82 or 3.8 [ignore 10^n] **(1)**
hence $3.8(2) \times 10^{26}$ W [ue] [allow 3.9 or 4] **(1)** 3

[6]

54. Forces within star

(i) 1. Fusion forces [allow 'pressure from nuclear reactions' or 'hydrogen burning'] or radiation / photon pressure **(1)**

2. Gravitational / Weight (not just gravity) **(1)**

(ii) Equal **(1)** 3

(iii) White dwarf & red giant differences

Any three from:

- Temperature: T_{wd} (6000K – 30000K) > T_{rg} (2000K – 5000K)
- Volume: $V_{rg} > V_{wd}$ – allow A / d / r / bigger
- Mass: e.g. $M_{wd} < 1.4\ M_\odot$ AND $(0.4M_\odot <)\ M_{rg} < 8m_\odot$
- Fusion (of He / heavier elements) in rg / no fusion in wd
- Luminosity: $L_{rg}\ [10^2 – 10^6] > L_{wd}\ [10^{-2} – 10^{-4}]$ in terms of $L_\odot$
- Wd is (core) remnant of rg / rg before wd stage
- Density: $\rho_{wd} > \rho_{rg}$ **(1) (1) (1)** Max 3

[no numerical values for any property – max 2/3]

(iv) Neutron star

Core remnants' mass **(1)**

Must be > 1.4 $M_\odot$ or < 2.5 $M_\odot$ **(1)** 2

[8]

55. When Sun was formed

(i) Attempted use of $L_{\odot} = 1.4\,L$ **(1)**
2.8×10^{26} W **(1)**

(ii) 1.06^2 used **(1)**
5.5×10^{18} m^2 / 5.5×10^{12} km^2 **(1)** 4

Show temperature change

(iii) $L = \sigma T^4 A$ (or implied) **(1)**

Correct substitution [ecf] **(1)**

Hence 5500 (K) [no ecf] **(1)**

Hence 5800 − 5500 [or 330, 308, 310] **(1)** 4

Wien's law

(iv) Use of $\lambda_{(max)}T = 2.90 \times 10^{-3}$ m K **(1)**
530 nm or 500 nm [no ue] **(1)**
$\Delta\lambda$ = 30 nm (when rounded to 1 s.f.) **(1)** 3

[11]

56. (a) Electromagnetic Doppler effect

Change in the frequency/wavelength (of the light/radiation from a source) **(1)**
because of relative motion between source and observer **(1)** 2
[If giving specific examples must cover both possibilities of change in frequency and relative motion eg describe red shift and blue shift]

(b) Hubble's conclusions

Any two from:

- (Recession) velocity $\propto$ galaxy distance [NOT stars]
- Red shift due to a galaxy moving away from Earth/observer
- Deduction of the expanding Universe [not the Big Bang] **(1) (1)** 2

[only penalise lack of galaxy **once**]

(c) Minimum velocity

$\Delta\lambda$= 660 (nm) − 390 (nm) = 270 (nm) **(1)**

Their $\Delta\lambda$/ their short $\lambda = v/c$ **(1)**

Correct substitution of $c = 3 \times 10^8$ (m s^{-1}) **(1)**

Maximum velocity = 2.1×10^8 (m s^{-1}) **(1)** 4

(d) Critical mean density

Density is large enough to prevent Universe expanding for ever **(1)**
but not too big to cause a collapse/contraction of the Universe **(1)** 2

[10]

57. (a) (i) Definition of law

EITHER
Equation given and all symbols defined **(1)** **(1)**
[For each symbol incorrectly defined −1 mark; 3 incorrect get zero, not −1]
OR
Force proportional to product of masses **(1)**
Force inversely proportional to square of distance between the masses **(1)** 2

(ii) Derivation

Set $mg = \frac{GMm}{r^2}$ hence $g = \frac{GM}{r^2}$ **(1)** 1

(iii) Graph

Starting point [R, g] **(1)**

(R, g) and ($2R$, $\frac{g}{4}$) plotted **(1)**

($3R$, $\frac{g}{9}$) and ($4R$, $\frac{g}{16}$) ~ plotted **(1)** 3

[Ignore the line joining origin to (R, g)]

(b) (i) Equipotential surface

Surface containing all points at the same (gravitational) potential (energy) **(1)** 1

(b) (ii) Drawing of equipotential surfaces
Three concentric circles drawn **(1)**
Increasing separation **(1)** 2

(c) Explanation
The weight / g must remain constant OR uniform gravitational **(1)**
field
(For this to be true) changes in height must be small **(1)** 2

[11]

58. (i) Its chemical composition / surface temperature **(1)**
(not velocity) 1

(ii) Use of $\Delta\lambda/\lambda = \upsilon/c$ [some substitution or rearrange] **(1)**
see λ = 440 or 400 **(1)**
= 1.36×10^{7} m s^{-1} **(1)**
[if bald answer: 1.43×10^{7} **(1)xx**; 1.4×10^{7} **(1)xx ;**
1.50×10^{7} **(1) (1)x;** 1.5×10^{7} **(1) (1)x**]
towards the Earth / us **(1)** 4

[5]

59. Number of protons and neutrons in isotope of cadmium

Protons: 48 **(1)**
Neutrons: (122 – 48) = 74 **(1)** 2

Process which occurs in a fission reaction

3 points, e.g.

- starts with large/heavy nucleus/atom
- nucleus captures/absorbs neutron
- (becomes) unstable
- splits into (two) smaller nuclei (and more neutrons)
- with emission of energy (from mass defect)
- increased binding energy (per nucleon) **(1) (1) (1)** 3

Calculation of change in mass

Use of $\Delta E = c^2\Delta m$ **(1)**

$\Delta m = \Delta E/c^2$

$\Delta m = 3.2 \times 10^{-11}$ J/(3 × 108 m s^{-1})^2

= 3.6×10^{-28} kg **(1)** 2

Calculation of number of fissions required each second

Correct use of efficiency **(1)**
e.g. fission energy required = 660 MW × 100/30 = 2200 MW

No. of fissions per second = 2200×10^{6} J/3.2×10^{-11} J = 6.9×10^{19} **(1)** 2

Why it is necessary to have a lot more fuel in nuclear reactor

2 points, e.g.

- reactor needs to run for longer than 1 second
- need sustained chain reaction
- fuel must last for years
- only a small proportion of U-235 undergoes fission
- only small proportion of uranium is U-235
- greater certainty/frequency of neutron collisions **(1) (1)** 2

[11]

60. (a) Graph

Falling concave curve **(1)**

Not intercepting *x*–axis or *y*–axis **(1)** 2

Two reasons

- light is scattered by dust (or air molecules)/refraction **(1)** [allow twinkling]
- some wavelengths are absorbed by atmosphere **(1)** 2

(b) Two spectra

β_{car} is bluish; β_{And} is reddish [not just different colours] **(1)** 1

Read off $\lambda_{max} \approx (760 – 770)$ nm [Beware 680 nm] **(1)**

Use of Wien's law **(1)**

Answer $T = 3800$ K [allow 3600 K to 4000 K] **(1)** 3

Calculation

Use $L = \sigma A T^4$ **(1)**

$A = 2.0 \times 10^{28}$ W ÷ (9300 $K^4 \times 5.67 \times 10^{-8}$ W m^{-2} K^{-4}) **(1)**

$= 4.7 \times 10^{19}$ m^2 **(1)** 3

Estimate

Attempt at areas giving ~ 7 × [(×5 – ×8) allowed] **(1)**

$= 1.4 \times 10^{29}$ W [$(1.0 – 1.6) \times 10^{29}$ W allowed] **(1)** 2

[13]

61. What is mean by MS star

One burning/fusing (H as fuel) **(1)** 1

Outline

Quality of written communication **(1)** 1

- fuses He/other elements AND becomes red giant **(1)**

[OR $\leq$0.4 $M_\odot$ not red giant/becomes white dwarf]

- ceases fusion AND becomes white dwarf **(1)**
- white dwarf fades to cold lump/becomes (specified colour) dwarf/no longer visible **(1)** Max 3

What determines whether ms star becomes a white dwarf

The mass of the star **(1)**

if mass star < 8 $M_\odot$ OR if mass core remnant < 1.4 $M_\odot$ **(1)** 2

[7]

62. Determine period of pulsation of star A

2.4 to 2.7 days **(1)**

with evidence of averaging **(1)** 2

Addition to graph

B is approximately the same height **(1)**
B has a longer period **(1)**
Shape – more steeply up than down **(1)** 3

Description

Measure period and hence work out luminosity **(1)**

Measure intensity **(1)**

Use $I = L/4\pi D^2$ **(1)** 3

[8]

63. (a) Hubble constant

Attempt to find gradient **(1)**
1.9×10^{-18} s^{-1} **(1)** 2

Distance of this galaxy from Earth

$\Delta\lambda = 37.3$ or see $(410 - 372.7)$ **(1)**

Use of $\Delta\lambda/\lambda = \upsilon/c$ **(1)**

Use of $\upsilon = Hd$ [$\upsilon = 3.0 \times 10^{7}$ m s^{-1}] **(1)**

1.6×10^{25} m **(1)** 4

[full ecf H = 2×10^{-18} s^{-1} $\rightarrow$ 1.5×10^{25} m]

(b) Balloon – position of three dots

P, Q, R further apart on larger balloon **(1)**

Approximately similar triangles, i.e. approx. isosceles with base approximately ½ of long sides **(1)** 2

How balloon can be used to model expansion of Universe

Quality of written communication **(1)**

Dots represent galaxies **(1)**

Balloon inflation represents expanding universe **(1)**

Dots further apart move apart faster, (as with galaxies) **(1)** 4

[12]

64. Ways in which white dwarf star differs from main seguence

Lower mass/volume/radius/(surface) area **(1)**

Fusion (burning) finished [Not luminosity] **(1)** 2

Fate of star after it has become a white dwarf
Cools (gradually)
until no longer visible/becomes dimmer/changes colour **(1)** 2

[Allow brown dwarf]

HR diagram

Any two from:

- temperature scale in reverse direction
- at least two reasonable T values shown/ eg 40 000, 10 000,4000)
- indication of log scale **(1) (1)** Max 2

(Single) star selected at $L/L_{\odot} = 1$ [≈ ± 2mm vertically by eye] **(1)** 1
(Region) W clearly below MS [No ecf on T] **(1)** 1
M to include top of MS **(1)** 1

Explanation

Quality of written communication **(1)**
Greater mass means greater luminosity or greater temperature or greater gravitational forces **(1)**

Burns hydrogen/fuel much faster **(1)**
Runs out of fuel quicker **(1)** 4

[13]

65. Temperatures of the two stars

They are similar/same **(1)**
because of Wien's law/same λ/f **(1)** 2

Greater radius

Deneb **(1)**
More luminous **(1)**
Refer to $\sigma A T^4$ and state T similar **(1)** 3

Which star will appear brighter?
Vega **(1)**
Use of $I = L/4\pi D^2$ **(1)**
One correct value: D = 8.8 OR V = 29 ($\times 10^{-9}$ W m^{-2}) **(1)**
Second correct value with unit **(1)** 4

[9]

66. Velocity of galaxy

Calculation of 7 or 11nm, **(1)**
Consistent values substituted in $\Delta\lambda/\lambda$ $\Delta\lambda$ must be 7 or 11 **(1)**
[Ignore 10^X errors]
5.0 or 5.12 $\times 10^6$ ms^{-1} (consequent mark) **(1)**
Moving away from the Earth/Milky Way/us/observer **(1)** 4

Estimation of distance of galaxy from Earth

Use of $\upsilon = Hd$ **(1)**
$d = 2.8\text{-}2.9 \times 10^{24}$ m [Allow e.c.f their υ above] **(1)** 2

[6]

67. Formula

$F = GMm/r^2$ **(1)** 1

Show that tan θ = $MR^2 / M_e r^2$

Horizontally $T\sin\theta = F_{\text{mountain}}$ and vertically $T\cos\theta = mg$ **(1)**
[OR vector diagram showing forces and θ]

Dividing equations [OR from vector diag.]: $\tan\theta = F_{\text{mountain}} \div mg$ **(1)**
and $F_{\text{mountain}} = GMm \div r^2$ and $mg = GM_em \div R^2$ **(1)**
so $\tan\theta = GMm/r^2 \div GM_em/R^2$ **(1)** 4

Value for gravitational constant, G

Volume = $4/3\pi R^3 = 4/3\pi\,(6.4 \times 10^6 \text{ m})^3 = 1.1 \times 10^{21}$ (m^3) **(1)**

$M_e = V\rho = 1.1 \times 10^{21} \text{ m}^3 \times 4.5 \times 10^3 \text{ kg m}^{-3} = 4.9 \times 10^{24}$ (kg) **(1)**

$$G = \frac{gR^2}{M_e} = \frac{3gR^2}{4\pi R^3\rho} = \frac{3g}{4\pi R\rho} = \frac{3 \times 9.8\,\text{m s}^{-2}}{4\pi \times 6.4 \times 10^6\,\text{m} \times 4.5 \times 10^3\,\text{kg m}^{-3}}$$

$= 8.1 \times 10^{-11}$ N m^2 kg^{-2} **(1)** 3

Reason for inaccuracy

Any one from:

- Maskelyne's density is incorrect
- Earth/mountain not uniform density
- (centre of) mass of mountain not known
- mountain is not spherical
- difficult to determine vertical / measure very small θ
- Earth not a perfect sphere / point mass **(1)** 1

Earth's core

Much denser than mountain **(1)** 1

[10]

68. (a) Stefan-Boltzmann law

T = absolute or Kelvin temperature/K **(1)**

[Not °K or k]

of surface **(1)**

Unit luminosity: watt/W **(1)** 3

(b) Graph

State Wien's law OR see evidence of $\lambda_{max} \times T$ **(1)**

at two different points to give same product [Ignore 10^{-6}] **(1)**

More than two points and allow 2.8 – 3.0 × 10^{-3} (mK) **(1)** 3

[No ue]

Surface temperature of star

Temperature = 7300 [7000 to 7500] [No ue] **(1)** 1

Luminosity calculation

Use of T^4 [7300 K^4] [e.c.f] **(1)**

$A = 4\pi r^2$ substitution correct **(1)**

(5.67×10^{-8} W m^{-2} K^{-4}) $\sigma T^4 A$ used [ecf any A, T] **(1)**

= (1.4 → 1.8) $\times 10^{25}$ (W) [No ecf] **(1)** 4

(7000 K) (7500K) [No ue]

Matter consumed

$\Delta E = c^2 \Delta m$ **(1)**

Substitute their L and 9×10^{16} m^2 s^{-2} [Beware $\Delta E = c\Delta m$ used] **(1)**

Mass = 1.8×10^8 (kg s^{-1}) [No ue] [ecf] [Range: 1.5 – 2.0 $\times 10^8$ allowed] **(1)** 3

[14]

69. (a) Select words

Cool **(1)**

High **(1)**

Surface area **(1)**

Off the main sequence **(1)** 4

Hertzsprung-Russell diagram

(i) Temperature scale "←" **(1)**

Values in range (20 000 K to 60 000 K) and (2000 K to 4000 K) and non-linear showing at least 3 values **(1)**

[e.c.f. scale in wrong direction]

(ii) Level with 10° marked Xs [Check with ruler if unsure] **(1)**

(iii) Region below MS marked W **(1)**

(iv) Region above MS marked R **(1)** 5

(b) <u>Recognition of supernova</u>

Extremely bright star [not "explosion"] **(1)**
Suddenly appearing/time reference **(1)** 2

<u>How supernova is formed</u>

Any three from:

- quality of written communication
- when star collapses/implodes
- shock <u>wave</u> / explosion blows <u>outer layers</u> away [both needed]
- (H) fusion ceases/other fusion begins
- <u>protons</u> combine with electrons to form neutrons **(1) (1) (1)** Max 3

[14]

70. (a) More than four radial lines/four symmetric lines **(1)**
Arrows inwards **(1)** 2

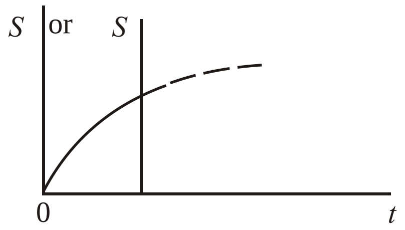
(b) Reference to speed of (gas) molecules [e.g. > 10 m s^{-1}] **(1)**
Greater than escape speed/υ_e **(1)** 2

(c) (i) m_A in kg *and* r_A in m **(1)**
N (in *G)* in kg m s^{-2}

(ii) $m_A = r_A \upsilon_e{}^2/2G$ **(1)**
$\Rightarrow m_A = 5.8 \times 10^{15}$ (kg) **(1)**
Use of $\rho = m/V$ *and* $V = 4/3\ \pi r^3$ **(1)** 5

$\Rightarrow \rho = 2900$ kg m^{-3} / 2940 kg m^{-3} [3018 kg m^{-3} from 6×10^{15} kg]

(d) (i) Size or volume of Universe/distance between galaxies against *t*/time **(1)**
Line rising which does not level off **(1)**
Big Bang/t = 0 labelled **(1)**



(ii) Average **(1)**
Density/mass-density (of Universe) **(1)** Max 4

(e) (i) Use of $\Delta p/m\Delta \upsilon = F\Delta t$ **(1)**
$\Delta \upsilon = (2 \times 10^6 \text{N})\ (7000 \text{ s}) \div 5.8/6 \times 10^{15}$ kg **(1)**
$= 2/2.3 \times 10^{-6}$ m s^{-1} **(1)**

(ii) Will/will not alter asteroid's course [No mark]
Justification: refer to $\Delta s = t\Delta \upsilon / s = \upsilon\, t$ **(1)** 4

[17]

71. <u>What *T* represents</u>

Surface temperature of star **(1)** 1

<u>Sun on diagram</u>

S correctly marked at $L / L_{sun} = 1$ **(1)** 1

<u>Flux calculation</u>

$L = 10^{-2} \times 3.9 \times 10^{26}$ W $= 3.9 \times 10^{24}$ W **(1)**
Use of $F = L/4\pi d^2$ **(1)**

$= 3.9 \times 10^{24}$ W$/4\pi \times (500 \times 3.09 \times 10^{16}$ m$)^2$
$= 1.3 \times 10^{-15}$ W m^{-2} **(1)** 3

Force which holds Sun together

Gravity **(1)** 1

How nuclear processes release energy

Any three from:

- Nuclear fusion
- When hydrogen nuclei combine to form helium
- There is a loss of mass [OR mass defect]
- This mass loss is converted to energy ($\Delta E = c^2 \Delta m$) **(1) (1) (1)** 3

Sun becoming red giant

(i) Recall of $F = Gm_1m_2/r^2$ [OR $g = GM/r^2$] **(1)**
Gravitational force does not change, since this depends on the mass of the Sun and distance to (centre of) Sun, which have not changed **(1)**

(ii) Arrow from S pointing right and upwards **(1)** 3

[12]

72. Topic A – Astrophysics

Red giant

Quality of written communication [needs $\geq$ 2 processes] 1

Any three from:

- Hydrogen burning ceases in core
- Core collapses/star collapses
- Star swells up/star expands
- other fusion processes occur in core/hydrogen burning takes place in 'shell' /outer layers Max 3

Wien's law

Star cooler/*T* less 1

Hence Wien' s law means λ_{max} greater 1

[e.c.f. *T* increases, hence λ_{max} decreases]

Stefan's law

Law states $L = \sigma AT^4$ OR $L \propto AT^4$ 1

Larger (surface) area A/radius/diameter 1

Increase in A > decrease in T^4 1

OR huge/massive increase in $A/r/d$ makes up for/compensates for decrease in T
[NOT just A increases more than T decreases]

[9]

73. Topic C – Particles

Binding energy

Quality of written communication 1

Energy required/ put IN to separate/break up a nucleus 1

Into protons + neutrons OR nucleons 1

OR in terms of energy given OUT when making a nucleus
OR mass defect between nucleus and separate nucleons

Graph

Shape [not bell-shaped; steeper rise than fall; start near origin; fall less than half max height] 1
Peak at around 50 [40 – 70] 1

Isotopes

BE/nucleon [any reference] 1
See working out, e.g. 7.72: 7.44 [no u.e.] 1
Hence O-16 ..I 1 1

[O-16 because O-17 is radioactive gets 1/3]

[8]

74. Frequency of spectral line for calcium

Use of $c = f\lambda$ 1

$f = 7.63 \times 10^{14}$ Hz 1

Ultra violet 1

Line spectrum

(A series of) lines on a dark /white background 1

Wavelength of calcium line

Use of $\Delta\lambda = \upsilon/c \times 393$ nm 1

393 ± 18 – 19 (nm) 1

λ = 411–2 nm 1

Hubble constant

See $365 \times 24 \times 60 \times 60/3.2 \times 10^7$ 1

Use of 3×10^8 [$d = 9.5 \times 10^{24}$] 1

Use of $\upsilon = Hd$ 1

$H = 1.50 \times 10^{-18}$ [no ue as unit given] 1

Recessional velocity

$\upsilon = 5.72 \times 10^7$ (ms^{-1}) [No u.e.] 1

[12]

75. Forces

(i) $F = GM_E m/R^2$ 1

(ii) $F = GM_M m/r^2$ 1

Distance R

$$\left.\begin{array}{c} \dfrac{GM_E m}{R^2} = \dfrac{GM_m m}{r^2} \\ \text{OR} \\ \dfrac{M_E}{M_m} = \dfrac{R^2}{r^2} \text{ OR } \left(\dfrac{M_E}{M_m}\right)^{1/2} = \dfrac{R}{r} \end{array}\right\}$$

$$\frac{81}{1} = \frac{R^2}{(3.9 \times 10^7 \text{ m})^2}$$

$R = 3.5 \times 10^8$ m

Evidence that equating forces has occurred 1

Correct substitution 1

Correct answer 1

[5]

76. Expression for gravitational force

$F = GMm/r^2$ **(1)** 1

Derived expression

Reasoning step must be clear, e,g, $mg = GMm/r^2$ **(1)**
so $g = GM/r^2$ **(1)** 2

Sun's gravitational field strength

$g = 6.67 \times 10^{-11}$ N m^2 kg^{-2} $\times 1.99 \times 10^{30}$ kg / $(1.50 \times 10^{11}$ m$)^2$ **(1)**

$= 5.9 \times 10^{-3}$ (N kg^{-1}) [no u.e.] **(1)** 2

Diagram

(i) Jupiter marked closest to Earth **(1)**

(ii) (Labelled) arrows towards Jupiter and Sun (radially) **(1)** 2

Maximum percentage change

$3.2 \times 10^{-7} / 5.9 \times 10^{-3} \times 100\% = 0.005\%$ **(1)** 1

Maximum value of the ratio

Use of $g \propto M/r^2$ **(1)**

Hence $g_{Venus}/g_{jupiter}$ **=** $15^2/400 = 0.56$ [OR 9/16] **(1)** 2

Comment

E.g. reference to % change caused by Jupiter (combined with effect caused by Venus)
OR g of (all) planets is **very** small compared with g of Sun **(1)** 1

[11]

77. Binding energy

Energy released when separate nucleons combine to form a **nucleus (1)** 1

[OR energy required to split **nucleus** into separate nucleons]

Binding energy of a nucleus of uranium-235

Reading from graph: 7.2 ± 0.2 MeV **(1)**

Hence binding energy $= 7.2 \times 10^6 \times 235 = 1.7 \times 10^9$ eV **(1)** 2

[Second mark is for multiplying graph reading by 235]

Energy released

Half-sized nucleus has binding energy/nucleon = 8.2 (± 0.2) MeV **(1)**

so released energy/nucleon = (8.2 – 7.2) × 10^6 × 1.6 × 10^{-19}

(=1.6 × 10^{-13} J) **(1)**

Total energy released = 235 × 1.6 ×10^{-13} J =3.8 × 10^{-11} J **(1)** 3

Energy released by fission

(2).6 × 10^{24} × 4.0 × 10^{-11}J **=** 1.0 × 10^{14} J

[Allow e.c.f from candidate's numbers, within range] **(1)** 1

[7]

78. Explanation

Any two from:

- signal attenuated through interaction with particles/asteroid
- signal diffracted on leaving transmitter
- not all of radio signal will be received by asteroid
- (reflected) signal spreads out (varying as $1/r^2$) **(2)** 2

Explanation of how reflected signal can be used to calculate speed

E.g.
frequency/wavelength of reflected signal changed **(1)**
Doppler Effect specified / Doppler equation given (with λ or f) **(1)**
all symbols in equation $\upsilon = c\ \Delta f / f_{\text{emitted}}$ explained **(1)** 3

Calculations

(i) Distance = speed × time

= 3.0 × 10^8 **×** 120

= 3.6 × 10^{10} m (for return journey)

Asteroid distance is 1.8 × 10^{10} m **(1)**

(ii) Time to reach Earth = distance ÷ speed

= 1.8 × 10^{10}/4000 [Allow e.c.f from (i)]

= 4.5 × 10^6 s

(= 52 days) **(1)**

Assuming that speed does not change (due to gravitational attraction of Earth) **(1)** 3

Explanation of why asteroid unlikely to collide with Earth

E.g. Earth will have moved around Sun
[Apply e.c.f from (ii)] **(1)** 1

[9]

79. Deduction

$F = m\upsilon^2/r$ / $mr\omega^2$ or accel/field strength = $\upsilon^2/r/r\omega^2$ **(1)**

$GMm/r^2 = m\upsilon^2/r$ or $mr\omega^2$ / $GM/r = \upsilon^2$ / $\upsilon^2 \alpha\ 1/r/ \frac{Gm}{r^2} = \frac{\upsilon^2}{r}$ **(1)**

So radius smaller than Earth/Sun or accompanied by "as T smaller"
/ "larger gravitational force" / "larger field strength" **(1)**

But $r_{PLANET} = 0.18 r_{earth}$ **(1)** Max 3

Discussion

Blue green – colours absorbed by (atmosphere/surface) of planet **(1)**

The spectrum of light given out by this star is different to ours **(1)**

Periodic bright/dull – planet orbiting Bootes implied (goes in front and behind) **(1)**

Dimmer when it goes in front/behind/argument based on reflection **(1)**

Varying wavelength Doppler shifted **(1)**

Relative movement produces change in frequency/wavelength **(1)** Max 4

[Max 6]

80. Luminosity of Sun

Attempt to use $I = L/4\pi D^2$

$L = 4\pi \times (1.5 \times 10^{11}\text{m})^2 \times 1.4 \times 10^3\ \text{W m}^{-2}$ [Ignore 10^3 error] **(1)**

$= 3.96$ [OR 4.0] $\times 10^{26}$ W [at least 2 s.f.] 3

Why intensity at top of atmosphere used

Atmosphere absorbs/scatters (some radiation)/reflects/filters
out/equivalent **(1)** 1

Estimate of energy released for each helium nucleus created

Δm = [4(1.67) –6.64] × 10^{-27} kg [Ignore 10^n error] **(1)**

= 0.04 × 10^{-27} kg **(1)**

$\Delta E = \Delta mc^2$ **(1)**

= 4 (OR 3.6) × 10^{-12} j [e.c.f. Δm] **(1)** 4

[If only ONE hydrogen atom in Δm**:** ecf to possible 3/4)]

Show number of nuclei

Number = $\dfrac{4\times10^{26}}{4\times10^{-12}}(=1\times10^{38})$ **(1)**

[ecf energy above even though ≠ 1×10^{38}]

Mass of hydrogen

Mass = $1\times10^{38} \times 4 \times 1.67 \times 10^{-27}$ kg **(1)**

OR $1 \times 10^{38} \times 6.64 \times 10^{-27}$ kg

= 7×10^{11} kg (6.6) **(1)** 2

[Again ecf ONE hydrogen atom → possible 1/2. If use their value for number of nuclei → possible 1/2]

[10]

81. Calculation of binding energy

Δm = 8 (1.007276 + 1.008665) u – 15.990527 u **(1)**

$\Delta E = \Delta m \times 930$ [Their Δm OR 0.137001 u) **(1)**

= 127.4 MeV [130]

[Answer in joule, max 2 out of 3] 3

Binding energy per nucleon

= answer above/16 [ecf joule also]

= 7.9 → 8.1 MeV [ecf] **(1)** 1

Graph

Steep rise and less steep fall; starts close to 0,0 and falls no more than ½ way to axis **(1)**

peaking in region 25 – 75 **(1)** 2

Positions on Graph

[for full marks. must be placed on or close to drawn line]

(i) O labelled at approximately 16 (½ way to 50) **(1)**
(ii) Fe labelled at peak, wherever it is **(1)**
(iii) U labelled at just short of 250 **(1)** 3

[9]

82. Hertzsprung-Russell diagram

x_A, x_B and x_C all marked **(1)** 1

α Ori – red giant **(1)**
Procy B – white dwarf **(1)**
β Per – main sequence **(1)** 3
[e.c.f. wrong *x* positions]

[If no *x*s on diagram, 3/3 for identifying still possible]

Calculations

Luminosity α Ori $= 6 \times 10^4 \times 3.8 \times 10^{26}$ W **(1)**

$= 5.67 \times 10^{-8}$ Wm^{-2} K^{-4} $\times$ A m^2 $\times (3500)^4$K^4 **(1)**

$A = 2.7 \times 10^{24}$ m^2 **(1)**

$A = 4\,7\pi r^2$ **(1)**
$R = 4.6 \times 10^{11}$ m [e.c.f. A] **(1)** 5

[9]

83. Light year
Is the distance travelled by light in one year **(1)** 1

Show that ly is equivalent to
Distance = speed × time [no mark]
(365 × 24 × 60 × 60) s OR 3.15×10^7 s **(1)**
$\times 3 \times 10^8$ m s^{-1} $= 9.5 \times 10^{15}$ (m) OR 9.4 **(1)** 2

[Accept “working backwards”, i.e. distance ÷ speed → time ≈ 3.15×10^7 s]

Explanation
A distant star does not seem to move **(1)**
against the background/with respect to a distant star **(1)**

OR

Angle between star and distant star **(1)**
does not change/difference in angles, too small to measure **(1)**

As the Earth moves over 6 months/June & January **(1)** Max 3

[Do not accept "angle too small to measure"; do not award 1 mark from top and 1 mark from bottom pair]

[6]

84. Supernova and description

- Quality of written communication **(1)**
- A star which *suddenly* becomes **(1)**
- very bright/luminous **(1)**
- Fusion/hydrogen burning ceases/runs out of hydrogen **(1)**

- Collapse of core/collapse of star/implosion **(1)**
- Outer layers bounce off core/shock wave/explosion **(1)**
- Blowing away outer layers **(1)**
- Nuclear reactions take place in outer layers/ejected material **(1)** Max 5

Fates for the central core remnant
Neutron star **(1)**
Black holes **(1)** 2

[7]

85. Base units of G: kg^{-1} m^3 s^{-2} **(1)**
Equation homogeneity:

Correct substitution of units of G, r^3 (m^3), M (kg) 1

leading to S^2 and linked to T^2 **(1)**
[Allow e.c.f. of their base unit answer into substitution mark] 3

Use of relationship to find mass of the Earth

Any two from:
Adding 20 000 + 6400 **(1)**
Converting km to m **(1)**
h to s (× 43 200) **(1)** 2
Answer $M = 5.8\ (4) \times 10^{24}$ kg **(1)** 1

[6]

86. Magnitude of gravitational force on Cassini

$F = GMm/r^2$ 1

Expression

$g = F/m$ **(1)**

so $g = GM/r^2$ **(1)** 2

Maximum acceleration

Appreciation that acceleration = g-field **(1)**

Addition of orbital height to radius of Venus **(1)**

$g = G \times 4.87 \times 10^{24}$ kg / $(6384 \times 10^3)^2$

= 7.97 m s^{-2} 3

Effect of acceleration on velocity of Cassini

Any 2 from:

- Acceleration is at right angles to direction of motion
- Speed unchanged
- (Velocity changed since) direction changed Max 2

Percentage change

Use of $\Delta f / f = \upsilon/c$ **(1)**

$= 12/3 \times 10^8$

so percentage change = $1200/3 \times 10^8 = 4 \times 10^{-6}$ **(1)** 2

[10]

87. Nuclear equations

X = 2 **(1)**

Z = 2 **(1)** 2

Physics of nuclear fission and fusion

Any 5 from the following:

- either/both transform mass into energy
- products formed have greater binding energy/nucleon
- either/both reaction(s) have a mass defect
- fission – splitting nucleus; fusion joining nuclei together
- fission used in nuclear reactors; fusion reactors not yet available
  [or only in bombs/stars]
- fusion needs high pressure and temperature/high energy particles
- fission forms radioactive products AND fusion forms stable products
- explanation of either involving strong nuclear force — Max 5

[7]

88. Peak wavelengths:

β Ori — $2.9 \times (10^{-3})$ m K
$1.1 \times (10^{4})$ K **(1)**
$= 2.6 \times 10^{-7}$ m OR 260 nm (263 nm) **(1)**

α Cet — 8.1×10^{-7} m OR 810 nm (805 nm, 800 nm) **(1)**

[Penalise "Not nanometres" once only] — 3

Power per square metre:
Attempt to use σT^4 (5.67 and 1.1^4 substituted) **(1)**
$= 8.3 \times 10^8$ (W m^{-2}) **(1)** — 2

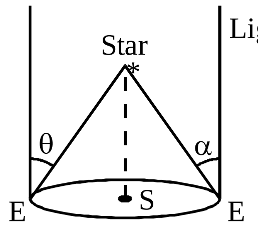
Labelled graph shows:
Ori peak at ~ 260 nm [e.c.f. their value] [Obviously to left of 400 nm] **(1)**
Cet peak at ~ 800 nm [e.c.f.] [Obviously to right of 700 nm] **(1)**

Area Ori » area Cet [e.c.f. their power] **(1)**
[Accept > 4 × height]
[irrespective of λ] — 3

Explanation:
[NB Refer to candidate's graph]
Ori at blue end of spectrum; Ceti at red end **(1)**
BOTH outside visible region [e.g. in ultraviolet, in infra-red, "near"] **(1)**
[Apply e.c.f. if wrong λs above] — 2

[10]

89. (a) Parallax diagram:



Labels on any FOUR of the following:

- distant stars labelled or implied e.g. by parallel lines
  [Accept without arrow heads]
- light from (nearby) star
- Earth orbiting Sun shown OR labelled June-January
- Angles α, θ labelled
- Angle P = distance Sun-Earth divided by distance to star OR
  trigonometry involving appropriate angle, sine and tangent, 1 all and D **(4)** 4

Suitability:
The difference in angles is too small to measure for
distant stars/distant stars do not move OR equivalent/we can
only measure angles to 1/100 arc sec **(1)** 1

(b) Supernova:
Quality of language **(1)**
Star → or begins as red giant **(1)**
H burning or fusion ceases/fuel used up **(1)**
Star collapses/contracts/shrinks/implodes **(1)**
Shock wave **(1)**
Blows off outer layers **(1)** Max 4

Remnant:
Becomes neutron star/black hole **(1)** 1

[10]

90. Explanation:
Doppler shift:
change in frequency/wavelength **(1)**
due to motion of source/galaxy/observer **(1)**

Galaxies:
The shift of a spectral line **or** use formula to find v. **(1)**
'Red shift' ⇒ receding **or** 'Blue shift' ⇒ approaching **(1)**
Quality of written communication **(1)** 5

Graph:
Shape rough parabola; must hit time axis. **(1)** 1

Experimental difficulties:
$\upsilon = Hd$[No mark]
d difficult to measure for distant galaxies **(1)**
Hence H is inaccurate/uncertain. [consequent] **(1)**
υ fairly accurately measured or H is squared so error bigger **(1)** 3

[9]

91. Calculation of energy released for each fission:

Δm = 0.2035u **(1)**

Convert their Δm to kg [$\times$ (1.66 $\times$ 10^{-27}) kg] OR $\times$ 931 **(1)**

Convert their kg to J [$\times (3 \times 10^8 \text{ m s}^{-1})^2$] OR $\times$ 1.6 $\times$ 10^{-13} **(1)**

= 3.04 $\times$ 10^{-11} (J) **(1)**
4

Calculation of power output:

Energy per mole = 3.04 $\times$ 10^{-11} J $\times$ 6 $\times$ 10^{23} **(1)**

Full e.c.f. their energy = 1.8 $\times$ 10^{13} J

Power = $\dfrac{\text{Any energy J}}{5\text{ s}}$ [No e.c.f.] **(1)**

= 3.6 $\times$ 10^{12} W [Accept J s^{-1}] **(1)**
3

[7]

[10]

92. Word equation:

Force proportional to product of masses and inversely proportional to (distance / separation) squared **(1)(1)**
2

[No force 0/2]

OR

$$F = \frac{G \times \text{mass}_1 \times \text{mass}_2}{(\text{distance})^2}$$ **(1)**

[or (separation)^2 instead of bottom line]

Calculation of force:

From Newton's law OR idea that force = weight = mg_{planet} **(1)**

$$F = \frac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6.42 \times 10^{23}\ \text{kg} \times 1\ \text{kg}}{(3.40 \times 10^6)^2\ \text{m}^2}$$

[Substitution in correct equation only]

OR

$$g_{\text{mars}} = \frac{G \times 6.42 \times 10^{23}\ \text{kg}}{(3.4 \times 10^6)^2\ \text{m}^2}$$ **(1)**

= 3.7 N **(1)**

Smaller **(1)**

3

Explanation of reasoning:

g is less, but ρ is similar/same [so R is less] **(1)**

[2nd mark is consequential on first mark]

2

[7]

93. H–R diagram:

Circle S on main sequence at $L_{\odot} = 10°$ **(1)**

Circle M on main sequence at top left **(1)** 2

Numbers on temperature axis showing increase ← **(1)**

Coolest 3000 ± 1000; hottest 20 000 – 50 000
[Both for the mark] **(1)** 2

Large mass stars:

They are brighter OR have greater luminosity OR are hotter (than the Sun) **(1)**

and burn up fuel/hydrogen quickly [Not energy] **(1)** 2

Calculation:

See $E = mc^2$ **(1)**

See $\dfrac{3.9 \times 10^{26} \text{ watts}}{(3 \times 10^8 \text{ m s}^{-1})^2}$ **(1)**

$= 4.3 \times 10^9 \text{ kg s}^{-1}$ **(1)** 3

[9]

94. Show that:

$F = GMm/r^2$ **(1)**

$= 6.9 \times 10^{24}$ (N) **(1)** 2

Calculation:

$a = F/M = 3.1 \times 10^{-6} \text{ m s}^{-2}$ **(1)** 1

Explanation:

Planet exerts gravitational force on star **(1)**

Planet revolves around star, so direction of force changes with time **(1)**

Diagram showing force (or effect of force on star due to planet) **(1)** 3

Speed of star:

Using $\upsilon = 2\pi r / T$ and $a = \upsilon / r$ **(1)**

$r = \upsilon T/2\pi$ so $a = 2\pi\upsilon / T$

so $\upsilon = aT / 2\pi$ **(1)**

$= 3.1 \times 10^{-6} \times 9.2 \times 10^7 \div 2\pi$ [allow ecf for a]

$= 45.4 \text{ m s}^{-1}$ 3

Calculation:

$\Delta\lambda = \lambda\, \upsilon/c = 656 \times 10^{-9} \times 45 / 3.0 \times 10^8$**(1)**

$= 9.8 \times 10^{-14}$m

[Accept $2 \times \Delta\lambda$ for maximum marks] **(1)** 2

[11]

95. Discussion:

Credit to be given for all good, relevant Physics

Examples of mark scoring points:

Universe may continue to expand **(1)**

or may collapse back on itself **(1)**

Fate depends on mass of Universe **(1)**

Since mass determines force/deceleration on moving stars **(1)**

So far, not enough mass has been found to stop expansion **(1)**

There may be matter present which is currently undetectable **(1)**

Nature of this dark matter

e.g. neutrinos, very hard to detect **(1)**

black holes, no light escapes **(1)**

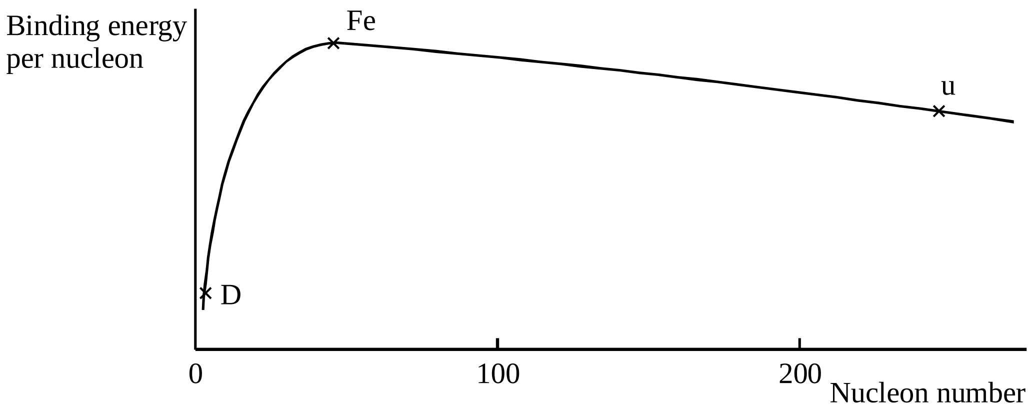
WIMPS explained **(1)**

neither expand nor collapse **(1)**

explained in terms of energy **(1)**

[Max 6]

96. Labels of elements:



D close to O: AND U $\geq$ 200 **(1)**

Fe at peak **(1)** 2

Meaning of binding energy:

Energy needed to split/separate a nucleus **(1)**

into protons and neutrons/nucleons **(1)**

OR

Energy released when nucleus formed **(1)**

from protons and neutrons/nucleons **(1)**

OR

Energy released due to mass change/defects **(1)**

Sum of masses of protons and neutrons > mass of nucleus **(1)**

[In each of the cases above, the second mark is consequent upon the first]

Explanation:

Uranium **(1)**

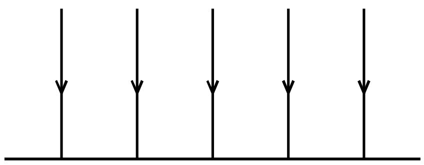
Binding energy per nucleon of products is higher
OR
Products/atoms/element/nuclei nearer peak **(1)**

Therefore more stable **(1)** 5

[7]

97. Draw diagrams to represent

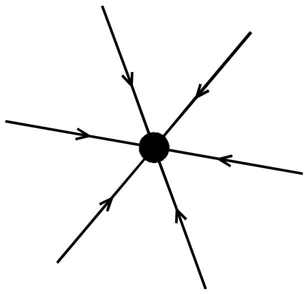
(i) the gravitational field near the surface of the Earth,



Direction

Lines: at least 3 parallel perpendicular equally spaced

(ii) the electric field in the region of an isolated negative. point charge.



Direction

Lines: at least 3 radial equally spaced

(4 marks)

How does the electric field strength *E* vary with distance *r* from the point charge?

E $\propto \frac{1}{r^2}$ **(1)**

(1 mark)

Give an example of a region in which you would expect to find a uniform electric field.

Between charged parallel plates (1).

(1 mark)
[Total 6 marks]