

Option E — Astrophysics

- E1.** (a) *constellation*: pattern of stars;
Candidates must indicate that stars are not close together.
stellar cluster: group of stars bound by gravitation / in same region of space; [2]
- (b) $d = \frac{1}{0.0077}$;
 = 130 pc [1]
- (c) no atmospheric turbulence / irregular refraction; [1]
- (d) (i) red/red-orange; (*not orange*)
 blue / blue-white / white; [2]
- (ii) Betelgeuse looks brighter; [1]
- (iii) $L = 4\pi bd^2$;
Rearrangement of formula on data sheet required.
 $d = 4.0 \times 10^{18}$ m;
 $L = 4\pi \times 2.0 \times 10^{-7} \times (4.0 \times 10^{18})^2$;
 $L = 4.0 \times 10^{31}$ W; [4]
- (iv) $L = 4\pi bd^2$
 luminosity of Rigel is about half that of Betelgeuse; (*or ECF from (iii)*)
 brightness of Rigel is about 0.1 times that of Betelgeuse;
 so Rigel is more distant; { (*must be a consistent conclusion from*
statements about luminosity and brightness) [3]
- Do not allow mark for fallacious or no argument.*
Award [1 max] for a mere statement that luminosity and brightness are less
so Rigel is more distant.
- E2.** (a) universe is infinite; [1]
- (b) number of stars in shell increases as R^2 ;
 intensity decreases as $\frac{1}{R^2}$;
 brightness of shell is constant;
 adding all shells to infinity;
 sky would be as bright as Sun / uniformly bright; [5]
Award [2 max] for argument based on any line of sight lands on a star.

- E3.** (a) low mass stars will finish burning helium (into carbon and oxygen);
and collapse to a white dwarf; *[2]*
- (b) high mass stars will finish burning (silicon) to iron;
and collapse into a neutron star / black hole; *[2]*
-
- E4.** (a) wavelengths are shifted;
universe is expanding / galaxies receding / Doppler Shift; *[2]*
- (b) statement of Hubble's law (*e.g.* $v = Hd$) with symbols explained;
 v obtained from spectral lines / Doppler Shift; *[2]*
- (c) the expansion of the universe is very small on local scales;
it would be impossible to distinguish between random velocities and expansion; *[2]*

Option H — Relativity

- H1.** (a) observers using rulers and clocks to measure positions and times of events;
these observers are not accelerating; [2]
- (b) (i) realization that 6.0 years is the proper time interval;
calculation of gamma factor $\gamma = \frac{1}{\sqrt{1-0.80^2}} = \frac{5}{3} (= 1.67)$;
time on Earth $\gamma \times 6.0 = 10$ yrs; [3]
- (ii) realization that spacecraft has been travelling for 10 years at $0.80c$;
so distance is $0.80c \times 10 = 8.0$ ly; [2]
- (iii) let t be the time according to the spacecraft observers, then in this time Earth
will move a distance of $0.80c \times t$ according to spacecraft;
Earth and spacecraft are already separated by $0.80c \times 6 = 4.8$ ly according
to spacecraft;
and so $ct = (0.80c \times t) + 4.8 \Rightarrow t = \frac{4.8}{0.20} = 24$ years; [3]

- H2.** $u_x' = \frac{(u_x - v)}{\left(1 - \frac{u_x v}{c^2}\right)}$
identifies u_x as $0.8c$;
identifies v as $-0.8c$;
to give answer of $0.98c$; [3]

- H3.** (a) *RME*: rest mass times c^2 ;
TE: sum of RME + kinetic energy (assuming no potential energy); [2]
- (b) 938 MeV ; [1]
- (c) $\gamma m_0 c^2 = m_0 c^2 + Ve$;
 $Ve = \gamma m_0 c^2 - m_0 c^2$
 $Ve = m_0 c^2 (\gamma - 1)$;
 $Ve = 938(4.0)$;
 $V = 3750 \text{ MV}$; [4]

- H4.** (a) (i) centre is single point to which all mass would collapse;
 surface is where the escape speed is equal to c ;
 within this surface, mass has “disappeared” from the universe; **[3]**
- (ii) distance from point of singularity to the event horizon / *OWTTE*; **[1]**
- (iii) $R_{\text{SCH}} = \frac{2GM}{c^2} = \frac{(2 \times 6.67 \times 10^{-11} \times 2 \times 10^{31})}{(3 \times 10^8)^2}$;
 $= 3.0 \times 10^4 \text{ m}$; **[2]**
- (iv) at 10^7 km , space is not warped;
 so Newtonian physics applies;
 any other good comment; **[2 max]**
Award [0] for a statement of “no” without justification.
- (b) theory suggests that light is affected by gravitational fields;
 diagrams or “words” to explain formation of two images; **[2]**