Mark scheme for Support Worksheet – Option H, Worksheet 2

1 The twin paradox refers to the situation in which a space traveller leaves Earth and a twin brother behind and embarks on a long space travel returning to Earth some time later. The Earth observer claims that the rocket observer aged less because he moved away. The rocket claims that he is ate rest and so the Earth observer aged less. [2]

2 The rocket observer changed his inertial frame of reference when he started on the return trip; this implies that he aged less. [2]

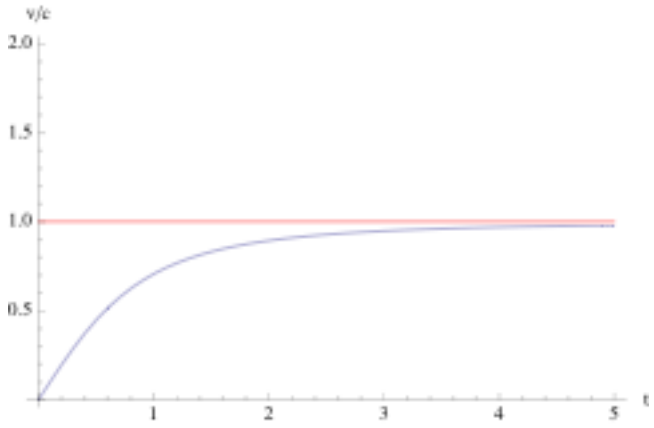
3 In the Hafele–Keating experiment accurate atomic clocks were put on a plane that travelled for a few hours; upon landing the clocks were compared with similar accurate clocks that were left behind; it was found that the clocks that were put on the plane recorded that less time had gone by. [3]

4 $u = \dfrac{u' + v}{1 + \dfrac{u'v}{c^2}} = \dfrac{(-0.40c) + 0.40c}{1 + \dfrac{(-0.40c)(0.40c)}{c^2}}$; so that $u = 0$ [2]

5 $u' = \dfrac{u - v}{1 - \dfrac{uv}{c^2}} = \dfrac{(0.60c) - 0.75c}{1 - \dfrac{(0.60c)(0.75c)}{c^2}}$; $u' = -0.27c$ [2]

6 **a** The work done in accelerating the proton is $W = qV = 1e \times 8.20 \times 10^8 \text{ V} = 820 \text{ MeV}$; and so the total energy of the accelerated proton is $E = 938 + 820 = 1758 \approx 1760 \text{ MeV}$ [2]

b The units on the time axis in the following graph are arbitrary.



[2]

c The graph is identical to what one would expect from Newtonian mechanics when the speed is low compared to the speed of light – we get a straight line; but as time passes the speed approaches the speed of light but never reaches it. [2]

7 The lifetime according to the observer in the lab is $\Delta t = \frac{2.2\times10^{-6}}{\sqrt{1-0.80^2}} = 3.67\times10^{-6}$ s ; so the distance travelled is $v\Delta t = 0.80c\Delta t = 0.80\times3.0\times10^{8}\times3.67\times10^{-6} \approx 880$ m [2]

OR lab moves a distance of $v\Delta\tau = 0.80c\Delta\tau = 0.80\times3.0\times10^{8}\times2.2\times10^{-6} = 528$ m according to muon; so distance in the lab is the proper distance and so is $\frac{528}{\sqrt{1-0.80^2}} = 880$ m [2]

8 From $E^2 = (mc^2)^2 + p^2c^2$, $1890^2 = 938^2 + p^2c^2$; so $p = \sqrt{1890^2 - 938^2} = 1640.8 \approx 1640$ MeV c^{-1} [2]

9 The momentum of X is $p_X = \frac{m\times0.80c}{\sqrt{1-0.80^2}} = 1.33mc$ and that of Y is $p_Y = \frac{2m\times0.40c}{\sqrt{1-0.40^2}} = 0.87mc$; hence $\frac{p_X}{p_Y} = \frac{1.33mc}{0.87mc} = 1.5$ [2]

10 The principle of equivalence states that it is impossible to distinguish the effects of gravitation from those of acceleration. [1]

11 Light bends towards a massive body; and time runs slower near a massive object. [2]

12 **a** **b**

[2]

13 **a** **b**

[2]