Mark scheme for Option H

1 **a** The speed of light in vacuum is the same for all inertial observers.

The laws of physics are the same for all inertial observers. **[2]**

Exam tip: do not forget the word **vacuum**.

b Earth: $\frac{12}{0.60} = 20\text{ y}$.

Rocket: $\gamma = \frac{1}{\sqrt{1-0.60^2}} = 1.25$.

Time for rocket is proper and so time is $\frac{20}{1.25} = 16\text{ y}$. **[3]**

c Earth: distance is 12 ly and signal travels at *c* so time is 12 y.

Rocket: in the time *t* it takes for the signal to arrive earth moved away a distance $0.60ct$.

Distance separating earth from P when signal leaves is $\frac{12}{1.25} = 9.6\text{ ly}$.

So $ct = 9.6 + 0.60ct \Rightarrow t = 24\text{y}$. **[4]**

2 **a** The length of an object measured in its rest frame. **[1]**

Exam tip: do **not** just say the length of an object at rest.

b **i** Light from the two explosions travels at the same speed and covers equal distances.

So if the light from the explosions arrives at the same time, the light was emitted at the same time. **[2]**

ii Light from the explosions reaches the train observer simultaneously according to the ground observer.

But train observer moves away from light from the left explosion.

Since light has a constant speed.

The light from the left must have been emitted first. **[4]**

Exam tip: you need to give a detailed and **logical** answer.

iii Both are equally correct in their measurements. **[1]**

c **i** Marks on the train:

Train observer: this is the proper length of the train, i.e. 240 m.

Ground observer: this is the train's contracted length with a gamma factor of $\gamma = \frac{1}{\sqrt{1-0.80^2}} = \frac{5}{3} = 1.667$.

And so $\frac{240}{1.667} = 144$ m. **[3]**

ii Marks on the ground:

Train observer: 240 m.

Ground observer: the distance d we want when contracted must give 240 m.

Hence $\frac{d}{1.667} = 240$ m and so $d = 1.667 \times 240 = 400$ m. **[3]**

3 **a** $\gamma = \frac{1}{\sqrt{1-0.980^2}} = 5.025$.

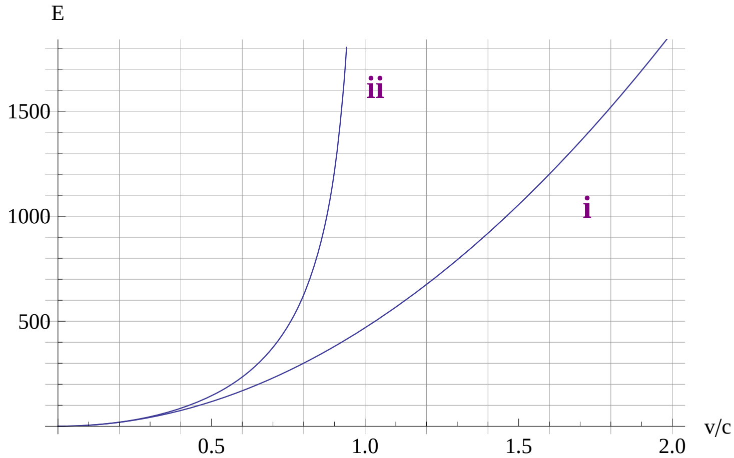
$E_K = (\gamma - 1)mc^2 = 4.025 \times 938 = 3.8\ \text{GeV}$.

Hence the potential is $V = 3.8\ \text{GV}$. **[3]**

b As the speed approaches *c* the energy of the proton tends to infinity.

And this is impossible. **[2]**

c **[1]** for each correct graph.



[2]

d **i** $u' = \frac{u - v}{1 - \frac{uv}{c^2}} = \frac{-0.90c - 0.90c}{1 - \frac{(-0.90c)\times(0.90c)}{c^2}}$; **[2]**

$u' = -0.994475c \approx -0.99c$

Exam tip: The question asks for speed so we must remove the minus sign.

ii $\gamma = \frac{1}{\sqrt{1-0.994475^2}} = 9.526$.

$E = \gamma mc^2 = 9.526 \times 938 = 8.9\ \text{GeV}$. **[2]**

iii 0 **[2]**

4 **a** **i** Inertial and gravitational effects are indistinguishable. **[1]**

Exam tip: For exam purposes this somewhat vague answer is acceptable but you must know the detailed versions of the principle.

ii A box at rest in a gravitational field is equivalent to a frame of reference accelerating in outer space.

In the accelerating box a ray of light directed initially parallel to the base of the box will hit the other side closer to the base.

Hence the ray of light has bent towards the massive body. **[3]**

Exam tip: You may want to draw a diagram here.

b **i** It will be the same.

A freely falling frame is equivalent to an inertial frame in outer space. **[2]**

ii It will be the same.

A freely falling frame is equivalent to an inertial frame in outer space. **[2]**

c The frequency at the base would be lower.

The light would hit the right wall higher up. **[2]**

5 **a** Space-time is the continuum in which physical phenomena take place.

A black hole is a singularity in this space-time/a point of infinite space-time curvature. **[2]**

b $R = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 4.0 \times 10^{35}}{9.0 \times 10^{16}} = 5.9 \times 10^{8}$ m. **[1]**

c Substitution $\frac{1}{2.8} = \frac{\frac{1}{6.4}}{\sqrt{1-\frac{R}{r}}}$.

$r = 1.24R$.

$r = 7.3 \times 10^{8}$ m. **[3]**