Mark schemes

1 (a) The laws of physics are the <u>same</u> in <u>all inertial</u> frames of reference OWTTE

Allow specified laws eg Newton's laws applies in all inertial frames of reference

Do not allow laws of physics are ***obeyed or apply***

Allow any / every inertial frame of reference

1

(b) (i) Converts 24 GeV to J $24 \times 10^9 \times 1.6 \times 10^{-19}$ or 3.84×10^{-9} (J) seen ✓

3.84×10^{-9} or $24 \times 10^9 = \dfrac{9.11\times10^{-31}\times(3\times10^8)^2}{\gamma}(-9.11\times10^{-31}\times(3\times10^8)^2)$ ✓

2.14 or 2.13×10^{-5} ✓ from correct working
at least 3 sf needed

Many convert to equivalent mass

4.27×10^{-26} and then work in masses throughout

May include the bracketed term. Depending on whether they assume 24 GeV to be the total energy or the kinetic energy

Allow incorrect powers of 10

May use given γ and find energy and compare with 24 GeV

3

(ii) $3000 \times 2.1 \times 10^{-5} = 0.063$ or 0.064 m ✓

1

(c) Starts at m_o ✓

Shallow increase to

- no more than 2 m_o at 0.7c
- curves (sharply) upwards becoming greater than 0.9 c at 6m_o
- never greater than 1.0 c
- within ½ square of 1.0 c at 12m_o ✓

Never greater than 1.0c

Allow statement of asymptote

2

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2 (a) (i) d_0 =(speed × time = $1.8 \times 10^8 \times 95 \times 10^{-9}$) = 17(.1) m ✓

1

(ii) d (= d_0 $(1 - v^2/c^2)^{½}$)

= $17.1 \times (1 - (1.8 \times 10^8/3.0 \times 10^8)^2))^{½}$ ✓

= 14 m ✓ (or 13.7 m or 13.68 m)

or

$t = t_0 (1 - v^2/c^2)^{-½}$

$95 = t_0 \times (1 - (1.8 \times 10^8/3.0 \times 10^8)^2)^{-½}$ gives t_0 = 76 ns ✓

$d = vt_0 = 1.8 \times 10^8 \times 76 \times 10^{-9}$ = 14 m ✓ (or 13.7 m or 13.68 m)

2

(b) m (= $m_0 (1 - v^2/c^2)^{-½}$)

= $1.67(3) \times 10^{-27} \times (1 - (1.8 \times 10^8/3.0 \times 10^8)^2)^{-½}$) ✓

= 2.09×10^{-27} kg ✓

kinetic energy = $(m - m_0)\,c^2$

or correct calculation of $E = mc^2$ (= 1.88×10^{-10} J)

or correct calculation of $E_0 = m_0c^2$ (= 1.50×10^{-10} J) ✓

$$\frac{\text{kinetic energy}}{\text{rest energy}} = \frac{(m - m_0)c^2}{m_0c^2} = \frac{(2.09 - 1.67) \times 10^{-27}}{1.67 \times 10^{-27}}$$ ✓

= 0.25 (allow 0.245 to 0.255 or ¼ or 1:4) ✓

5

[8]

3

(a) (i) (use of $v = \frac{d}{t}$ gives) $v = \frac{240}{0.84 \times 10^{-6}}$ = 2.8(6) × 10^8 m s^{-1} **(1)**

(ii) actual length = 240 m **(1)**

(use of $l = l_0\left(1 - \frac{v^2}{c^2}\right)^{1/2}$ gives)

length in particle frame, $l = 240\left(1 - \frac{2.86^2}{3^2}\right)^{1/2}$ **(1)**

(allow C.E. for value of v)

l = (240 × 0.30) = 72(.5) m **(1)**

4

(b) time between two events depends on speed of observer

[or $t = t_0\left(1 - \frac{v^2}{c^2}\right)^{1/2}$ or rocket time depends on speed of traveller] **(1)**

traveller's journey time is the proper time between start and stop

[or t_0 is the proper time or t is the time on Earth] **(1)**

journey time measured on Earth > journey time measured by traveller

[or $t > t_0$ or rocket time slower / less than Earth time] **(1)**

traveller younger than twin on return to Earth **(1)**

4

[8]

4

(a) (i) $l = (vt = 1.00 \times 10^8 \times 15 \times 10^{-9})$ = 1.50m **(1)**

(ii) $\left(l = l_0\sqrt{1 - \frac{v^2}{c^2}}\right)$

$1.50 = l_0\sqrt{1 - \frac{(1.00 \times 10^8)^2}{(3.00 \times 10^8)^2}}$ **(1)**

$l_0\left(= \frac{1.50}{0.943}\right)$ = 1.59 m **(1)**

3

(b) (i) $m = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}}$ **(1)** $\left[\text{or } \dfrac{m_0}{\sqrt{1-\dfrac{(1.00\times10^8)^2}{(3.00\times10^8)^2}}}\right]$

$m\left(\text{or } \dfrac{m_0}{\sqrt{1-\dfrac{(1.00\times10^8)^2}{(3.00\times10^8)^2}}}\right) = 1.06m_0$

[or = $1.06 \times 1.67 \times 10^{-27}$ or 1.77×10^{-27} kg] **(1)**

kinetic energy = $(m - m_0)c^2$ **(1)**

[or = $0.06m_0c^2$ or $0.06 \times 1.67 \times 10^{-27} \times (3 \times 10^8)^2$]

= 9.1×10^{-12} (J) **(1)**

(ii) total k.e. = $(10^7 \times 9.1 \times 10^{-12}) = 9.1 \times 10^{-5}$ (J) **(1)**

k.e. per second $\left(= \dfrac{9.1\times10^{-5}}{1.5\times10^{-9}}\right)$ = 6080W

max 5

[8]

5 (a) (i) speed of light (in free space) independent of motion of source **(1)**
and of motion of observer **(1)**
[*alternative (i)*
speed of light is same in all frames of reference **(1)**]

(ii) laws of physics have same form in all inertial frames **(1)**
inertial frame is one in which Newton's 1 st law of motion obeyed **(1)**
laws of physics unchanged in coordinate transformation
from one inertial frame of reference to any other inertial frame **(1)**

(max 4)

(b) (i) $m\left(= m_0\left(1-\dfrac{v^2}{c^2}\right)^{-\frac{1}{2}}\right) = 1.88 \times 10^{-28}\,(1-(0.996)^2)^{-\frac{1}{2}}$ **(1)**

= 2.10×10^{-27} kg **(1)**

(ii) $t_0 = 2.2 \times 10^{-6}$ s **(1)**

$$t\left(= t_0\left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}\right) = 2.2 \times 10^{-6}\,(1 - (0.996)^2)^{-\frac{1}{2}}\ \text{(s)}$$ **(1)**

$= 2.46 \times 10^{-5}$ (s) **(1)**

$s(= vt = 3.00 \times 10^{8} \times 0.996 \times 2.46 \times 10^{-5}) = 7360$ m **(1)**

[*alternative (ii)*
$l\ (= vt = 0.996 \times 3.0 \times 10^{8} \times 2.2 \times 10^{6}\ ) = 657$ (m) **(1)**

correct substitution of l in $l = l_0\sqrt{1 - \frac{v^2}{c^2}}$ **(1)**

$$l_0\left(= \frac{l}{\sqrt{1 - \frac{v^2}{c^2}}}\right) = \frac{657}{\sqrt{1 - 0.996^2}}$$ **(1)**

$l_0 = 7360$ m **(1)**

(6)
[10]