Mark scheme for Support Worksheet – Option H, Worksheet 1

1 A coordinate system used to record the position and time of events. [1]

2 A frame of reference that is not accelerating. [1]

3 **a** In the Y frame $x' = x - vt = 15 - 20 \times 2 = -25$ m and $t' = t = 2.0$ s [2]

b It is permissible since the speed of frame Y is very small compared to the speed of light and so Galilean relativity is approximately true. [1]

4 The speed of light in vacuum is constant (for all inertial observers); and the laws of Physics are the same for all inertial observers. [2]

5 The two events must take place at the same point in space. [1]

6 **a** The emissions are simultaneous for the ground observer because they are simultaneous for the box observer and take place at the same point in space. [1]

b the two light signals travel towards the walls with the same speed (*c*); but the left wall is approaching the left moving signal (whereas the right wall is moving away from the right moving signal); hence the left wall will receive the signal first. [3]

7 The observer on the ground measures that the rays of light reach the box observer at the same time; the rays move at the same constant speed; since the box observer moves away from the left signal and yet receives it at the same time as the right signal, the left signal must have been emitted first according to the ground observer. [3]

8 The time interval between two events that occur at the same point in space. [1]

9 Use of the light clock as described in *Physics for the IB Diploma* pages 652–653. [3]

10 $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-0.980^2}} = 5.0$ [1]

11 $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \Rightarrow 1-\frac{v^2}{c^2} = \frac{1}{\gamma^2}$; so $\frac{v}{c} = \sqrt{1-\frac{1}{\gamma^2}} = \sqrt{1-\frac{1}{3.25^2}} = 0.951$ [2]

12 Realisation that $\Delta t = \frac{\Delta\tau}{\sqrt{1-\frac{v^2}{c^2}}}$ with $\Delta\tau = 1.20$ s being the proper time interval; hence

$\Delta t = \frac{1.20}{\sqrt{1-0.70^2}}$; and so $\Delta t = 1.68$ s [3]

13 Realisation that $\Delta t = \dfrac{\Delta\tau}{\sqrt{1-\dfrac{v^2}{c^2}}}$ with $\Delta t = 5.4\times10^{-8}$ s, the proper time $\Delta\tau$ being measured by the ground observers; hence $5.4\times10^{-8} = \dfrac{\Delta\tau}{\sqrt{1-0.92^2}}$; and so

$\Delta\tau = 2.1\times10^{-8}$ s [3]

14 Proper length is the length of an object according to an observer with respect to whom the object is at rest. [1]

15 **a** The observer inside the rocket measures the proper length i.e. 120 m. [1]

b The observer on the ground measures $120\times\sqrt{1-0.90^2} = 52$ m [2]

16 **a** The length with respect to the ground is $60\times\sqrt{1-0.60^2}$; and this is 48 m. [2]

b The length with respect to an observer in the other rocket is $60\times\sqrt{1-0.88^2}$; and this is 28 m. [2]

17 This can be done in 2 ways. **Method 1**: the distance between the star and Earth is $4.2\times\sqrt{1-0.82^2} = 2.4$ ly according to the rocket observers; so star will arrive at the position of the rocket observer after $\dfrac{2.4\text{ ly}}{0.82c} = 2.9$ yr [2]

Method 2: according to the Earth observers the rocket will get to the star in $\dfrac{4.2\text{ ly}}{0.82c} = 5.12$ yr; so according to the rocket observers (who measure proper time interval) $\sqrt{1-0.82^2}\times5.12 = 2.9$ yr [2]