Physics Learning Activity

November 13, 2012

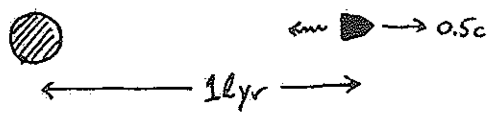
Name: SOLUTIONS
Student Number:
Bamfield Number:

Questions 1-9: Multiple Choice: 2 point each
Questions 10-12: Show your work: 20 points total

Multiple choice answers:

#1	
#2	
#3	
#4	
#5	
#6	
#7	
#8	
#9	

Formula sheet at the back (you can remove it)

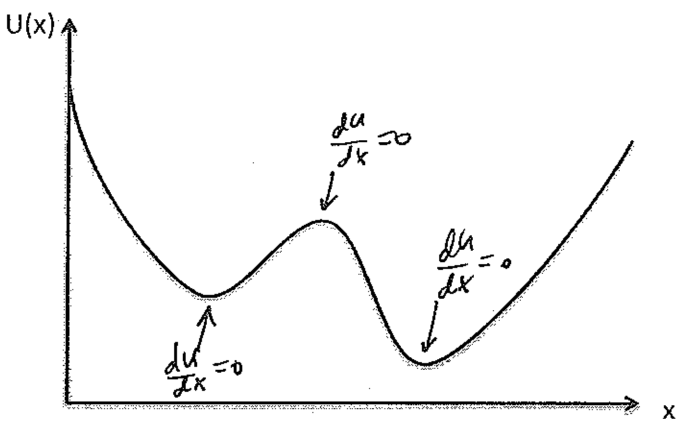


Question 1: A rocket traveling at 0.5c turns on its lights when it reaches a distance of 1 light year away from the Earth (in Earth's frame). How long does the light from the rocket take to reach Earth (in Earth's frame)?

speed of light is c regardless of the motion of the source, so

$$T = \frac{1\ \text{lyr}}{c} = 1\ \text{year}$$

A) one year
B) less than one year
C) more than one year



We have:

$$F_x = -\frac{dU}{dx}$$

$$F_x = 0 \text{ when } \frac{dU}{dx} = 0$$

Question 2: The graph above shows the potential energy of an object for various possible positions along the x direction. For how many positions x would the force on the object be zero?

A) 0 B) 1 C) 2 D) 3 E) 4

Question 3: A new kind of particle is produced in a particle accelerator. In the experiment the new particles are always produced traveling at v = 0.8c, and are observed to decay after they have traveled a distance of 3 meters on average. We can conclude that the half life of the new particle is closest to

A) 0.6×10^{-8} seconds
B) 0.8×10^{-8} seconds
C) 1.0×10^{-8} seconds
D) 1.25×10^{-8} seconds
E) 1.67×10^{-8} seconds

$v = 0.8c \Rightarrow \gamma = \frac{5}{3}$

3m

time for decay in lab's frame of reference:

$$T = \frac{3\ \text{m}}{0.8 \times 3 \times 10^8\ \text{m/s}} = 1.25 \times 10^{-8}\ \text{s}$$

time in particle's frame (proper time) $= \frac{1}{\gamma} \times T$

$$= \frac{3}{5} \cdot 1.25 \times 10^{-8}\ \text{m/s} = 0.75 \times 10^{-8}\ \text{s}.$$

Question 4: A bullet collides with a block on a frictionless table and sticks inside the block. In this collision, which quantities are conserved for the system of bullet and block (ignoring effects related to the air)?

No external forces in x direction ⇒ momentum conserved

A) Momentum, mechanical energy, and total energy
B) Momentum and total energy but not mechanical energy
C) Mechanical energy and total energy but not momentum
D) Only momentum
E) Only total energy

No transfer of energy to air or table
⇒ total energy conserved
Mechanical energy NOT conserved since inelastic (energy → heat of block)

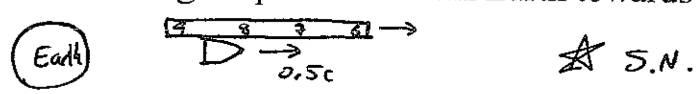
Question 5: The mass of a water molecule is:

A) less than the mass of an oxygen atom plus two hydrogen atoms
B) equal to the mass of an oxygen atom plus two hydrogen atoms
C) greater than the mass of an oxygen atom plus two hydrogen atoms

Water is a stable molecule.

Need to add energy to separate into O + H + H, so
E (water molecule) < E(H) + E(H) + E(O) ⇒ $m_{H_2O}c^2 < m_Hc^2 + m_Oc^2 + m_Hc^2$.

Question 6: A distant supernova explodes. In the frame of reference of the Earth, the explosion is simultaneous with the start of the Science One Learning Activity. In the frame of reference of a rocket travelling at speed 0.5c from Earth towards the supernova,

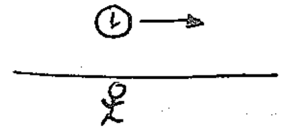


clocks in rocket's frame observed to read earlier time if further along direction of motion, so time for S.N. in rocket's frame less than time for start of Learning Activity

A) the supernova explodes after the Science One Learning Activity begins.
B) the supernova explodes before the Science One Learning Activity begins.
C) the supernova explodes at the same time as the Science One Learning Activity begins.
D) the answer could be A,B, or C depending on the location of the rocket.

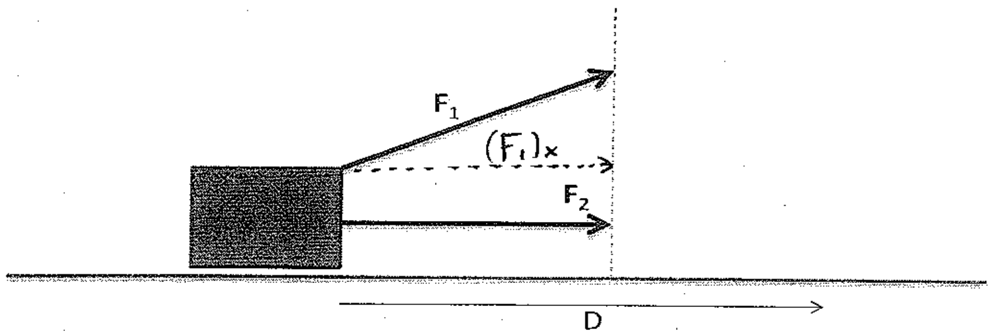
Question 7: In order to make the GPS (global positioning system) work correctly, engineers make the clocks on the orbiting satellites run at a different rate from clocks on Earth so that they appear to be ticking at the same rate as the Earth clocks. In order for this to work, the engineers should make the orbiting clocks run

A) Faster than the clocks on Earth
B) Slower than the clocks on Earth



if clocks ran at same rate, moving one would be observed to run slow. So need to make GPS clocks run faster than clocks on Earth.

(ignore effects related to the rotation of the Earth and to general relativity)



Question 8: A block is pulled a distance D across a frictionless surface using either the constant force F_1 or the constant force F_2. The work done on the block would be

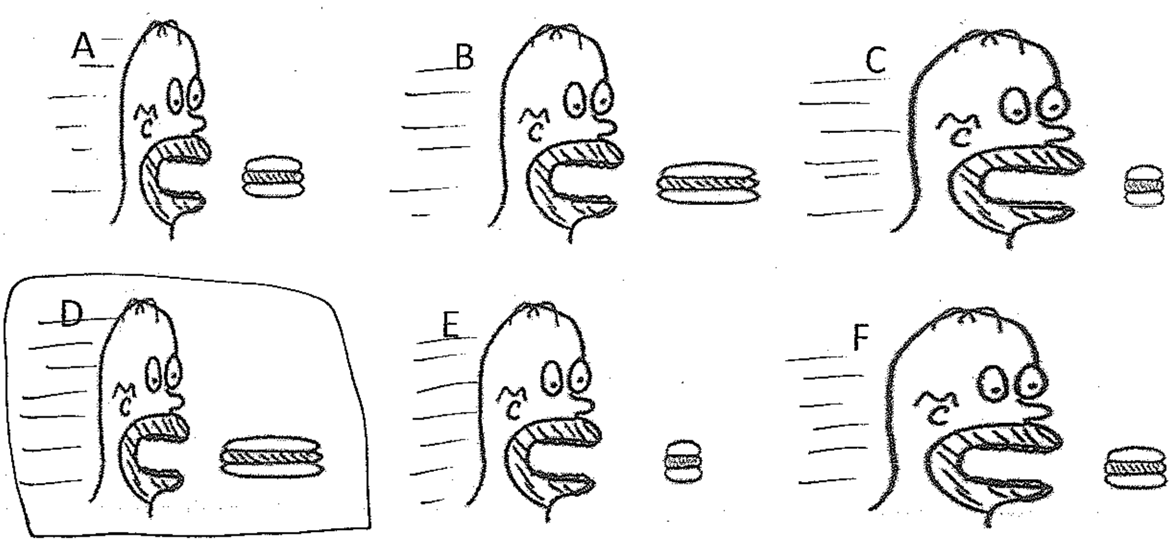
A) greater for the force F_1
B) greater for the force F_2
C) the same nonzero value in either case
D) equal to zero in either case

Work done is $\vec{F}\cdot\Delta\vec{r}$

$= |F_x| \cdot D$

same for both.

Question 9: Homer Simpson would like to eat a large hot dog in one bite, but finds that the distance between the front and back of his mouth is less than the length of the hot dog. Based on his knowledge of Einstein's theory of Special Relativity, Homer decides to fire the hot dog towards his mouth at a relativistic speed to take advantage of length contraction. If the picture at the left shows this scenario in Homer's frame of reference, which of the other pictures best represents the scenario in the hot dog's frame of reference?

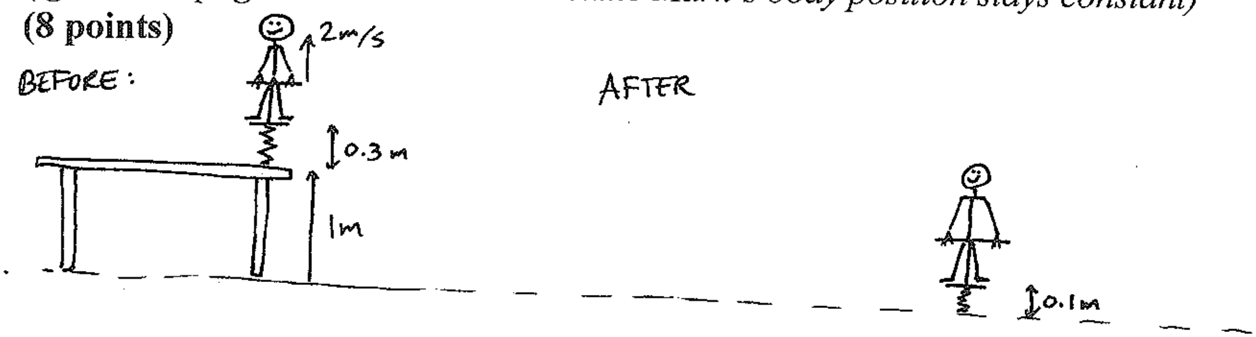


Homer will be contracted along his direction of motion.
Hot dog will be larger than in top picture

Question 10:

For a physics demo, Mark (mass 75kg) brings in a pogo stick with a spring on the bottom that has a normal length of 30cm. Mark stands with the pogo stick at the edge of a 1m high table and jumps upward off the table. If his vertical speed is 2m/s when the bottom of the spring leaves the table and the spring compresses to 10cm when Mark hits the ground (at the lowest point of his bounce), what is the spring constant? (*ignore the pogo stick's mass and assume Mark's body position stays constant)*

(8 points)



Mechanical energy is conserved, so we have

$$E_{BEFORE} = E_{AFTER}$$

v=0 at lowest point.
(Δs) =0 before.

$$\frac{1}{2}mv^2 + mgh_{BEFORE} = mgh_{AFTER} + \frac{1}{2}k(\Delta s)^2$$

$$\Rightarrow \frac{1}{2}k\cdot(0.3m - 0.1m)^2 = mg(h_{BEFORE} - h_{AFTER}) + \frac{1}{2}mv^2$$

$$\Rightarrow k\cdot(0.02\,m^2) = (75kg)(9.8\,m/s^2)(1.3m - 0.1m) + \frac{1}{2}(75kg)\cdot(2m/s)^2$$

$$\Rightarrow k\cdot(0.02m^2) = 882\,kg\,m^2/s^2 + 150\,kg\,m^2/s^2$$

$$\Rightarrow k = \frac{1032\,kg\,m^2/s^2}{0.02\,m^2}$$

$$= 5.16\times10^4\,kg/s^2 \leftarrow N/m$$

Question 11:

A space probe designed to observe the interstellar medium is sent from Earth at velocity v = (3/5)c. The probe is programmed to take data and transmit it back to Earth after 1 year has passed on the probe's clock.

a) How long after the probe leaves Earth should astronomers expect to receive the data transmission from the probe?
(5 points)

$\longrightarrow v = \frac{3}{5}c \quad \Rightarrow \gamma = \frac{5}{4}$

In the Earth's frame of reference, the probe's clock is observed to run slow, so the Earth time when the probe sends back its signal is

$$T = 1_{\text{year}} \times \gamma$$
$$= \frac{5}{4} \text{ years}$$

3

At this time, the probe's distance from Earth (in Earth's frame) is

$$D = \frac{5}{4} \text{ years} \times \frac{3}{5} c = \frac{3}{4} \text{ light years.}$$

1

The light travels this distance in $\frac{3}{4}$ years, so the time from when the probe leaves Earth to when the light signal returns is

1

$$\frac{5}{4} \text{ years} + \frac{3}{4} \text{ years} = 2 \text{ years.}$$

Question 12: A particle of mass M traveling at u=4/5c decays into two particles of identical mass m, one of which is at rest after the decay. Determine the mass m (relative to M) and the velocity of the moving particle after the decay. **(4 points)**

Energy and momentum are conserved, so we have:

$$E_{BEFORE} = E_{AFTER} \Rightarrow \gamma_u M c^2 = mc^2 + \gamma_v m c^2 \qquad (1)$$

$$P_{BEFORE} = P_{AFTER} \Rightarrow \gamma_u M u = \gamma_v m v \qquad (2)$$

Our unknowns are: m and v

Solve for m using equation (1):

$$m = \frac{\gamma_u M}{1+\gamma_v} \qquad (3)$$

Plug into equation (2):

$$\cancel{\gamma_u M} u = \gamma_v \cdot v \cdot \frac{\cancel{\gamma_u M}}{1+\gamma_v}$$

$$\Rightarrow u = \frac{v \cdot \frac{1}{\sqrt{1-v^2/c^2}}}{1 + 1/\sqrt{1-v^2/c^2}} = \frac{v}{1+\sqrt{1-\frac{v^2}{c^2}}}$$

$$\Rightarrow \sqrt{1-\frac{v^2}{c^2}} = \frac{v}{u} - 1$$

$$\Rightarrow -\frac{v^2}{c^2} = \frac{v^2}{u^2} - 2\frac{v}{u}$$

$$\Rightarrow v\left(\frac{1}{u^2} + \frac{1}{c^2}\right) = \frac{2}{u}$$

$$\Rightarrow v = \frac{2}{u}\left(\frac{1}{u^2} + \frac{1}{c^2}\right)^{-1} = \boxed{\frac{40}{41} c}$$

using (3),

$$m = \frac{\gamma_u}{1+\gamma_v} \cdot M = \frac{\frac{5}{3}}{1+\frac{41}{9}} \cdot M$$

$$\Rightarrow \boxed{m = \frac{3}{10} M}$$

b) In the frame of the probe, what does the probe's clock read when this data signal is received back on Earth, and what is the position of the Earth in the frame of the probe when this happens?
(3 points)

In Earth's frame, the light signal returns to Earth at $t = 2$ years, and the position of this event is $x = 0$.

In the probe's frame, the position and time of this event are

$$x' = \gamma(x - vt)$$
$$= \frac{5}{4}\left(-\frac{3}{5}c \cdot 2\text{years}\right)$$
$$= -\frac{3}{2} \text{ light years.}$$

$$t' = \gamma\left(t - \frac{v}{c^2}x\right)$$
$$= \frac{5}{4} \cdot 2\text{years}$$
$$= \frac{5}{2} \text{ years.}$$

ALTERNATE:

In probe's frame, Earth's clock is observed to run slow, so the probe's clock reads $\gamma \cdot (2\text{yrs}) = \frac{5}{2}$ years when the Earth's clock reads 2yrs. In this $\frac{5}{2}$yrs, the Earth moves a distance $\frac{5}{2}\text{years} \times \frac{3}{5}c = \frac{3}{2}$ lyrs.