This print-out should have 36 questions. Multiple-choice questions may continue on the next column or page – find all choices before answering.

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**AP B 1993 MC 40**
**001 10.0 points**

The operator of a space station observes a space vehicle approaching at a constant speed $v$. The operator sends a light signal at speed $c$ toward the space vehicle.

What is the speed of the light signal as viewed from the space vehicle?

**1.** $c^2/v$

**2.** $c$ **correct**

**3.** $c - v$

**4.** $c\sqrt{1 - \dfrac{v^2}{c^2}}$

**5.** $c + v$

**6.** $\dfrac{v}{\sqrt{1 - \dfrac{v^2}{c^2}}}$

**Explanation:**

All inertial observers, regardless of their state of motion, will always measure the speed of light to be $c$.

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keywords:

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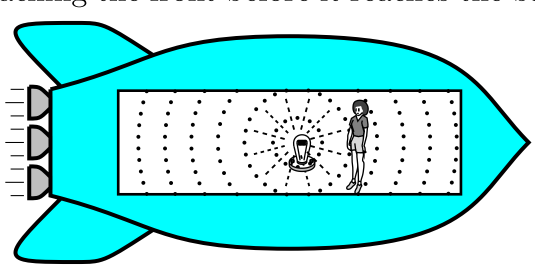
**Concept 35 10**
**002 10.0 points**

Suppose that the light bulb in the rocket ship (shown in the figures below) is closer to the front than to the rear of the compartment, so that the observer in the ship sees the light reaching the front before it reaches the back.

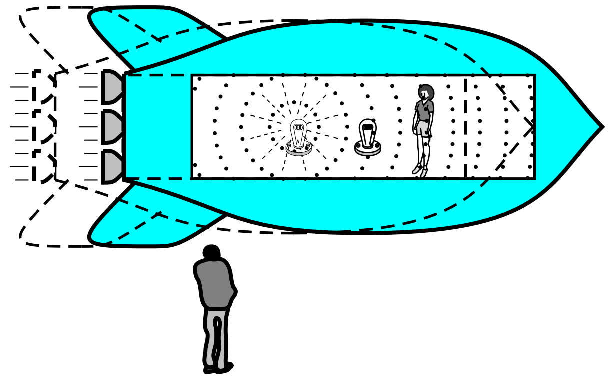


Is it still possible that an outside observer will see the light reaching the back first?

**1.** Yes **correct**

**2.** No

**Explanation:**



If the distance the rocket ship moves forward in the time it takes the light to reach the rear is greater than the distance by which the light bulb was shifted, the outside observer will still see the light reaching the rear first. You can see this, too, by considering such a tiny displacement of the light bulb that it makes hardly any difference to the outside observer, who still sees the light reaching the rear first. But to the inside observer, the light will reach the front first no matter how tiny the displacement was.

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**Conceptual 28 08**
**003 10.0 points**

Calculate the Lorentz factor for objects traveling at 18.1% of the speed of light.

Correct answer: 1.01679.

**Explanation:**

$$\text{Let :} \quad v = 0.181\, c\,.$$

$$\gamma = \frac{1}{\sqrt{1 - \left(\dfrac{v}{c}\right)^2}} = \frac{1}{\sqrt{1 - (0.181)^2}} = \boxed{1.01679}\,.$$

---

**Concept 35 05**
**004 10.0 points**

Why did Michelson and Morley at first consider their experiment a failure?

**1.** They did not have the equipment they originally wanted.

**2.** They did not measure the exact quantities.

**3.** They ignored the experimental errors.

**4.** They did not confirm the expected result. **correct**

**Explanation:**

Michelson and Morley considered their experiment a failure in the sense that it did not confirm the result that was expected. The difference in the speed of light was expected to be measured. The experiment was successful in the sense that it opened the door to new physics.

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**Concept 35 02**
**005 10.0 points**

If you were in a smooth-riding train with no windows, could you sense the difference between uniform motion and rest or between accelerated motion and rest?

**1.** Only uniform motion can be sensed.

**2.** No motion can be sensed.

**3.** Both acclerated and uniform motion can be sensed.

**4.** Only accelerated motion can be sensed. **correct**

**Explanation:**

Only accelerated motion, and not uniform motion, can be sensed. You could not detect your motion when traveling uniformly or when at rest, but accelerated motion could be easily detected by observing that the surface of the water in any container is not horizontal.

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**Concept 35 19**
**006 10.0 points**

If you were in a rocket ship traveling away from the Earth at a speed close to the speed of light, what changes would you note in your pulse? In your volume?

**1.** No changes because of time dilation

**2.** Faster pulse and larger volume

**3.** Slower pulse and smaller volume

**4.** No changes; you observed yourself in the same reference frame. **correct**

**Explanation:**

If you were in a high-speed (or no speed!) rocket ship, you would note no changes in your pulse or in your volume. This is because the relative velocity between the observer (yourself) and the observed is zero. No relativistic effect occurs for the observer and the observed when both are in the same reference frame.

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**Conceptual 28 05**
**007 (part 1 of 2) 10.0 points**

Elliot is traveling by a building at $1.7 \times 10^5$ km/s, moving along the width of the building. He measures the building to be 57 m wide and 92 m tall.

What is the width of the building as measured by a friend standing at rest next to the building? The speed of light is $3 \times 10^8$ m/s.

Correct answer: 69.1792 m.

**Explanation:**

$$\begin{aligned}\text{Let :}\quad & d = 57\text{ m}\,,\\ & c = 3\times10^8\text{ m/s}\,,\quad\text{and}\\ & v = 1.7\times10^5\text{ km/s} = 1.7\times10^8\text{ m/s}\,.\end{aligned}$$

The Lorentz factor is

$$\begin{aligned}\gamma &= \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}\\ &= \frac{1}{\sqrt{1-(\frac{1.7\times10^8\text{ m/s}}{3\times10^8\text{ m/s}})^2}} = 1.21367\end{aligned}$$

To Elliot, the building appears to be contracted by a factor of 1.21367 in the direction he is moving. Thus the width is

$$w = \gamma\, d = 1.21367(57\text{ m}) = \boxed{69.1792\text{ m}}.$$

**008 (part 2 of 2) 10.0 points**

What height of the building would be measured by the friend?

Correct answer: 92 m.

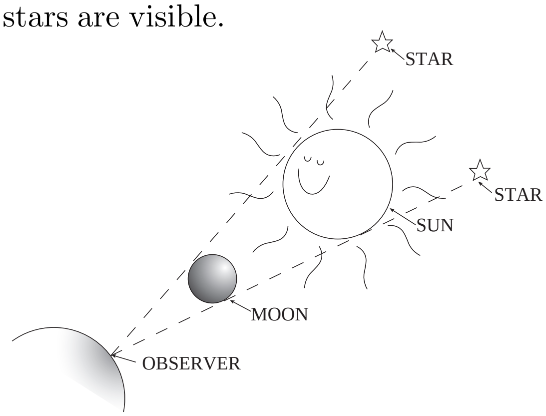
**Explanation:**

To Elliot, the building's height is not affected; so $h = \boxed{92\text{ m}}$.

keywords:

**Figuring Physics 07**
**009 10.0 points**

Assume the sun passes between the Earth and a pair of stars as shown, and the moon passes in front of the sun and totally eclipses it so the stars are visible.




According to general relativity, the stars will appear to be slightly

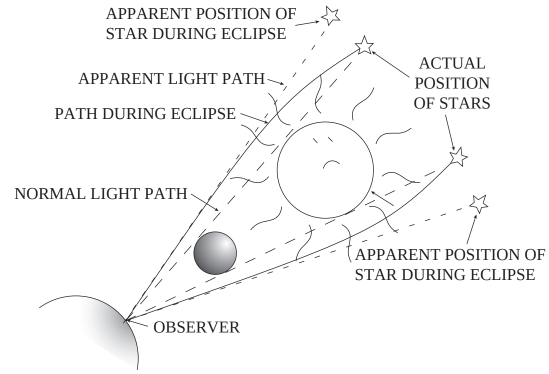
**1.** farther apart. **correct**

**2.** distorted, but not closer or farther apart.

**3.** closer together.

**Explanation:**

Light from the stars that grazes the sun bends as shown.




Consequently, the stars appear slightly farther apart.

This was predicted by Einstein in 1916 and tested during the total eclipse of the sun in 1919. It was an exciting confirmation of Einstein's General Theory of Relativity.

keywords:

**Length Contraction 03**
**010 10.0 points**

A spaceship is measured to be 172 m long while at rest relative to the observer.

If this spaceship now flies by the observer with a speed 0.985 times the speed of light, what length does the observer measure?

Correct answer: 29.6793 m.

**Explanation:**

$$\text{Let}: \quad L_p = 172\text{ m} \quad \text{and} \\ v = 0.985\,c\,.$$

If $L_p$ is the proper length of the moving object, the length of the spacecraft measured by the observer is

$$L = L_p \sqrt{1 - \frac{v^2}{c^2}} = (172\text{ m})\sqrt{1-(0.985)^2} \\ = \boxed{29.6793\text{ m}}.$$

**Relativity 02**
**011 10.0 points**

At what speed would you have to move past a 6.92 cm ruler so that you would observe its length to be 3.46 cm? The speed of light is $3 \times 10^8$ m/s.

Correct answer: 0.866025 $c$.

**Explanation:**

$$\text{Let :}\quad L' = 3.46 \text{ cm} \quad \text{and}$$
$$L = 6.92 \text{ cm}\,.$$

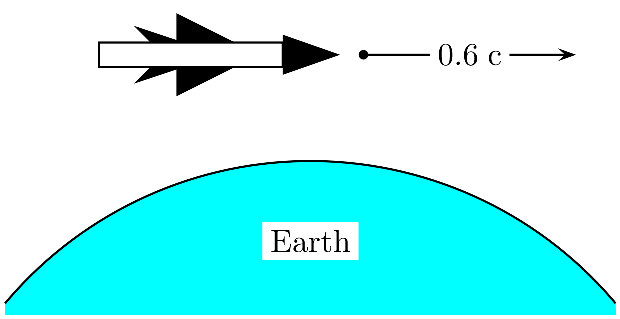
$$L' = L\sqrt{1-\left(\frac{v}{c}\right)^2}$$
$$\left(\frac{L'}{L}\right)^2 = 1 - \frac{v^2}{c^2}$$
$$v^2 = \left(1 - \frac{L'^2}{L^2}\right)\ c^2$$
$$= \left[1 - \frac{(3.46 \text{ cm})^2}{(6.92 \text{ cm})^2}\right]\ c^2$$
$$= 0.75\ c^2$$
$$v = \sqrt{0.75\ c^2} = \boxed{0.866025 \text{ c}}\,.$$

keywords:

**AP B 1994 FR 3b**

**012 (part 1 of 3) 10.0 points**

A spaceship travels with a speed of $0.6\,c$ as it passes by the Earth on its way to a distant star, as shown in the diagram below. The pilot of the spaceship measures the length of the moving ship as 30 m.




Determine its length as measured by a person on Earth.

Correct answer: 24 m.

**Explanation:**

$$\text{Let :}\quad L_0 = 30 \text{ m} \quad \text{and}$$
$$v = 0.6\,c\,.$$

Applying length contraction,

$$L = L_0\,\gamma$$
$$= L_0\sqrt{1-\frac{v^2}{c^2}}$$
$$= (30 \text{ m})\sqrt{1-\frac{(0.6\,c)^2}{c^2}} = \boxed{24 \text{ m}}\,.$$

**013 (part 2 of 3) 10.0 points**

The pilot of the spaceship observes that the spaceship travels for 2 years.

Determine how much time has passed according to a person on Earth.

Correct answer: 2.5 years.

**Explanation:**

$$\Delta T = \frac{\Delta T_0}{\gamma}$$
$$= \frac{2 \text{ years}}{0.8} = \boxed{2.5 \text{ years}}\,.$$

**014 (part 3 of 3) 10.0 points**

Some time after passing the Earth, the pilot shoots a laser pulse backward at a speed of $3 \times 10^8$ m/s with respect to the spaceship.

Determine the speed of the laser pulse as measured by a person on Earth.

Correct answer: $3 \times 10^8$ m/s.

**Explanation:**

A laser pulse travels at the speed of light, independent of the frame in which it is measured ( the key point of special relativity). Thus the Earth observer sees the pulse traveling at the same speed as the pilot, $\boxed{3 \times 10^8 \text{ m/s}}$.

**Concept 35 36**

**015 10.0 points**

Muons are elementary particles that are formed high in the atmosphere by the interactions of cosmic rays with atomic nuclei in the upper atmosphere. They receive a lot of energy from the original cosmic ray and travel at speeds close to the speed of light. Muons have an average lifetime of about two millionths of a second and according to classical physics should decay before reaching the sea level. Laboratory measurements, however, show that muons in great number do reach the Earth's surface.

What is the explanation?

**1.** Experimental physics is wrong.

**2.** Muons interact with some particles in the air.

**3.** Muons travel faster as they enter the lower atmosphere.

**4.** The timing in the muons' frame of reference is different from ours. **correct**

**Explanation:**

At $0.995c$ the muon has ten times as much time, or twenty-millionths of a second, to live in our frame of reference. From the stationary Earth, the muons's "clock" is running ten times slower than Earth clocks, allowing sufficient time for a muon to make the trip. From the muon's frame of reference, the distance to Earth is contracted by ten times, so it has sufficient time to get there.

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**Conceptual 28 04**
**016 10.0 points**

Anna is watching the stars late at night when she sees a spaceship pass at 88.5% of the speed of light; 14 seconds pass on Earth while she observes a clock on the spaceship.

How much time passes on the spaceship clock?

Correct answer: 6.51827 s.

**Explanation:**

$$\text{Let :} \quad v = 0.885\, c \quad \text{and} \quad t = 14 \text{ s}\,.$$

The Lorentz factor is

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1 - (0.885)^2}} = 2.14781\,,$$

so the ship time she observes is slower by this factor, and

$$t' = \frac{t}{\gamma} = \frac{14 \text{ s}}{2.14781} = \boxed{6.51827 \text{ s}}$$

pass on the ship's clock.

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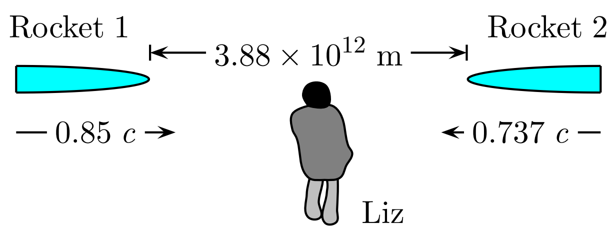
**Rocket Collision Course**
**017 (part 1 of 5) 10.0 points**

Two futuristic rockets are on a collision course. Rocket 1 is moving with speed 0.85 $c$ and rocket 2 is moving with speed 0.737 $c$. They are initially $3.88 \times 10^{12}$ m apart as measured by Liz, an Earth observer, as shown. Both rockets are 67.4 m in length as measured by Liz.




What is the proper length of rocket 1?

Correct answer: 127.946 m.

**Explanation:**

$$\text{Let :} \quad v = 0.85\, c \quad \text{and} \quad \ell = 67.4 \text{ m}\,.$$

$$\gamma_u = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{1}{\sqrt{1 - (0.85)^2}} = 1.89832\,.$$

so the proper length of rocket 1 is

$$\ell_1 = \gamma_v\, \ell = (1.89832)\,(67.4 \text{ m}) = \boxed{127.946 \text{ m}}\,.$$

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**018 (part 2 of 5) 10.0 points**

What is the proper length of rocket 2?

Correct answer: 99.72 m.

**Explanation:**

$$\text{Let :} \quad u = 0.737\ c\,.$$

$$\gamma_u = \frac{1}{\sqrt{1 - \dfrac{u^2}{c^2}}} = \frac{1}{\sqrt{1 - (0.737)^2}} = 1.47952\,,$$

so the proper length of rocket 2 is

$$\ell_2 = \gamma_u\,\ell = (1.47952)\,(67.4\ \text{m}) = \boxed{99.72\ \text{m}}\,.$$

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**019 (part 3 of 5) 10.0 points**

What is the length of rocket 1 as measured by an observer in the other rocket?

Correct answer: 28.009 m.

**Explanation:**

The relative velocity of the two rockets is

$$w = \frac{u+v}{1+u\,v} = \frac{0.737\ c + 0.85\ c}{1 + (0.737\ c)(0.85\ c)} = 0.975745\ c\,, \quad \text{so}$$

$$\gamma_w = \frac{1}{\sqrt{1 - \dfrac{w^2}{c^2}}} = \frac{1}{\sqrt{1 - (0.975745)^2}} = 4.56806\,.$$

The length of rocket 1 as observed from the other rocket is

$$L_1 = \frac{\ell_2}{\gamma} = \frac{\ell_1}{\gamma_w} = \frac{127.946\ \text{m}}{4.56806} = \boxed{28.009\ \text{m}}\,.$$

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**020 (part 4 of 5) 10.0 points**

According to Liz, how long before the rockets collide?

Correct answer: 8154.99 s.

**Explanation:**

Liz sees the initial gap of $3.88 \times 10^{12}$ m between the rockets decreasing at a rate

$$u + v = 0.737\ c + 0.85\ c\,,$$

so according to her, the time before collision is

$$T = \frac{L}{u+v} = \frac{3.88 \times 10^{12}\ \text{m}}{(0.737 + 0.85)\,(2.998 \times 10^8\ \text{m/s})} = \boxed{8154.99\ \text{s}}\,.$$

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**021 (part 5 of 5) 10.0 points**

According to rocket 2, how long before they collide?

Correct answer: 5511.9 s.

**Explanation:**

Here we can simply use the time dilation formula to determine the time experienced by rocket 2 during the same interval that Liz measures:

$$T = \gamma\,T_2$$
$$\Rightarrow T_2 = T/\gamma = \sqrt{1 - 0.737\ c^2}\,T \approx \boxed{5511.9\ \text{s}}\,.$$

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**Consequences of Relativity 11**

**022 10.0 points**

Find the momentum of a particle with a mass of one gram moving with half the speed of light.

Correct answer: $1.73205 \times 10^5$ kg · m/s.

**Explanation:**

$$\text{Let :} \quad v = 0.5\,c \quad \text{and} \quad m = 1\ \text{g} = 10^{-3}\ \text{kg}\,.$$

$$p_R = \gamma\,m\,v = \frac{m\,(0.5\ c)}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \frac{(10^{-3}\ \text{kg})0.5(3 \times 10^8\ \text{m/s})}{\sqrt{1 - (0.5)^2}} = \boxed{1.73205 \times 10^5\ \text{kg} \cdot \text{m/s}}\,.$$

**Consequences of Relativity 12**
**023 10.0 points**

A certain particle is at rest with respect to you.

Assuming that you measure its mass to be 4 g, what is its energy? 1 eV = $1.6 \times 10^{-19}$ J.

Correct answer: $2.25 \times 10^{27}$ MeV.

**Explanation:**

$$\text{Let}: \quad m = 4 \text{ g} = 0.004 \text{ kg} \quad \text{and} \quad c = 3 \times 10^8 \text{ m/s}.$$

$$\begin{aligned} E &= m\,c^2 \\ &= (0.004 \text{ kg})(3 \times 10^8 \text{ m/s})^2 \\ &\quad \times \frac{1 \text{ MeV}}{1.6 \times 10^{-13} \text{ J}} \\ &= \boxed{2.25 \times 10^{27} \text{ MeV}}. \end{aligned}$$

**Kangluo Relativity 33**
**024 (part 1 of 3) 10.0 points**

A proton moves at a speed of 0.86 $c$.

Find its rest energy.

Correct answer: $1.50362 \times 10^{-10}$ J.

**Explanation:**

$$\text{Let}: \quad m_p = 1.673 \times 10^{-27} \text{ kg} \quad \text{and} \quad c = 2.99792 \times 10^8 \text{ m/s}^2.$$

The rest energy is

$$\begin{aligned} E_{rest} &= m_p\,c^2 \\ &= (1.673 \times 10^{-27} \text{ kg}) \\ &\quad \times (2.99792 \times 10^8 \text{ m/s}^2)^2 \\ &= \boxed{1.50362 \times 10^{-10} \text{ J}}. \end{aligned}$$

**025 (part 2 of 3) 10.0 points**

Find its kinetic energy.

Correct answer: $1.44295 \times 10^{-10}$ J.

**Explanation:**

$$\text{Let}: \quad v = 0.86\,c.$$

$$\begin{aligned} \gamma &= \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1 - (0.86)^2}} \\ &= 1.95965, \quad \text{so} \end{aligned}$$

$$\begin{aligned} K &= (\gamma - 1)\,m_p\,c^2 = (\gamma - 1)\,E_{rest} \\ &= (1.95965 - 1)\,(1.50362 \times 10^{-10} \text{ J}) \\ &= \boxed{1.44295 \times 10^{-10} \text{ J}}. \end{aligned}$$

**026 (part 3 of 3) 10.0 points**

Find its total energy.

Correct answer: $2.94657 \times 10^{-10}$ J.

**Explanation:**

The total energy is

$$\begin{aligned} E &= K + E_{rest} \\ &= 1.44295 \times 10^{-10} \text{ J} + 1.50362 \times 10^{-10} \text{ J} \\ &= \boxed{2.94657 \times 10^{-10} \text{ J}}. \end{aligned}$$

**Mass Energy**
**027 (part 1 of 2) 10.0 points**

A mass of 0.472 kg is converted completely into energy of other forms.

How much energy of other forms is produced? The speed of light is $2.99792 \times 10^8$ m/s.

Correct answer: $4.24212 \times 10^{16}$ J.

**Explanation:**

$$\text{Let}: \quad m = 0.472 \text{ kg} \quad \text{and} \quad c = 2.99792 \times 10^8 \text{ m/s}.$$

$$\begin{aligned} E &= m\,c^2 = (0.472 \text{ kg})(2.99792 \times 10^8 \text{ m/s})^2 \\ &= \boxed{4.24212 \times 10^{16} \text{ J}}. \end{aligned}$$

**028 (part 2 of 2) 10.0 points**
How long will this much energy keep an 87.4 W lightbulb burning?

Correct answer: $1.53909 \times 10^7$ years.

**Explanation:**

$$
\begin{aligned}
P &= \frac{E}{t} \\
t &= \frac{E}{P} = \frac{4.24212 \times 10^{16}\ \mathrm{J}}{87.4\ \mathrm{W}} \\
&\quad \times \frac{1\ \mathrm{h}}{3600\ \mathrm{s}} \cdot \frac{1\ \mathrm{d}}{24\ \mathrm{h}} \cdot \frac{1\ \mathrm{y}}{365\ \mathrm{d}}, \\
&= \boxed{1.53909 \times 10^7\ \text{years}}.
\end{aligned}
$$

keywords:

**Rest Energy of a Particle**
**029 (part 1 of 4) 10.0 points**
The total energy of a particle is 4.42 times its rest energy. The mass of the particle is $2.8 \times 10^{-27}$ kg.

Find the particle's rest energy. The speed of light is $2.99792 \times 10^8$ m/s and $1\ \mathrm{J} = 6.242 \times 10^{12}$ MeV.

Correct answer: 1570.81 MeV.

**Explanation:**

$$
\begin{aligned}
\text{Let :}\quad m &= 2.8 \times 10^{-27}\ \mathrm{kg} \quad \text{and} \\
c &= 2.99792 \times 10^8\ \mathrm{m/s}.
\end{aligned}
$$

The rest energy of the particle is

$$
\begin{aligned}
E_0 = m\,c^2 &= (2.8 \times 10^{-27}\ \mathrm{kg}) \\
&\quad \times (2.99792 \times 10^8\ \mathrm{m/s})^2 \\
&\quad \times \frac{6.242 \times 10^{12}\ \mathrm{MeV}}{1\ \mathrm{J}} \\
&= \boxed{1570.81\ \mathrm{MeV}}.
\end{aligned}
$$

**030 (part 2 of 4) 10.0 points**
With what speed is the particle moving?

Correct answer: $2.92019 \times 10^8$ m/s.

**Explanation:**

$$
\begin{aligned}
\text{Let :}\quad E &= n\,E_0 \quad \text{and} \\
n &= 4.42.
\end{aligned}
$$

$$
\begin{aligned}
E &= \gamma\, m\, c^2 \\
n\,E_0 &= \gamma\, E_0 \\
n &= \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}} \\
1 - \frac{u^2}{c^2} &= \frac{1}{n^2}.
\end{aligned}
$$

$$
\begin{aligned}
u &= c\,\sqrt{1 - \frac{1}{n^2}} \\
&= (2.99792 \times 10^8\ \mathrm{m/s})\,\sqrt{1 - \frac{1}{4.42^2}} \\
&= \boxed{2.92019 \times 10^8\ \mathrm{m/s}}.
\end{aligned}
$$

**031 (part 3 of 4) 10.0 points**
Determine the kinetic energy of the particle.

Correct answer: 5372.16 MeV.

**Explanation:**
The kinetic energy of the particle is obtained by subtracting the rest energy from the total energy:

$$
\begin{aligned}
K = E - m\,c^2 &= 4.42\,m\,c^2 - m\,c^2 \\
&= (3.42)\,E_0 = (3.42)(1570.81\ \mathrm{MeV}) \\
&= \boxed{5372.16\ \mathrm{MeV}}.
\end{aligned}
$$

**032 (part 4 of 4) 10.0 points**
What is the particle's momentum?

Correct answer: $6762.95$ MeV$/c$.

**Explanation:**

$$\begin{aligned} E^2 &= (n\,m\,c^2)^2 = p^2\,c^2 + (m\,c^2)^2 \\ p &= m\,c\,\sqrt{n^2 - 1} \\ &= \frac{m\,c^2}{c}\,\sqrt{n^2-1} \\ &= \frac{1570.81\text{ MeV}}{2.99792 \times 10^8\text{ m/s}}\,\sqrt{4.42^2 - 1} \\ &= \boxed{6762.95\text{ MeV}/c}\,. \end{aligned}$$

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keywords:

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**Concept 36 12**
**033 10.0 points**

If we witness events taking place on the moon, where gravitation is weaker than on Earth, would we expect to see a gravitational red shift or a gravitational blue shift?

**1.** No shift; events run at the same speed on the moon and Earth.

**2.** Red shift; events on the moon run slower than on Earth.

**3.** Blue shift; events on the moon run faster than on Earth. **correct**

**4.** It depends on the speed of event.

**Explanation:**
Events on the moon, as monitored from the Earth, run a bit faster and are slightly blue shifted. And even though signals escaping the moon are red shifted in ascending the moon's gravitational field, they are blue shifted even more in descending to the Earth's stronger $g$ field, resulting in a net blue shift.

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**Concept 36 19**
**034 10.0 points**

Is light emitted from the surface of a massive star red-shifted or blue-shifted by gravity?

**1.** No shift

**2.** It depends on the mass of star.

**3.** Red shifted **correct**

**4.** Blue shifted

**Explanation:**
Light emitted from the star is red shifted. This can be understood as the result of gravity slowing down time on the surface of the star, or as gravity taking energy away from the photons as they propagate away from the star.

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**Concept 36 22**
**035 10.0 points**

How can we *observe* a black hole if neither matter nor radiation can escape from it?

**1.** We can use X-ray telescopes which are very sensitive to very short wavelengths.

**2.** We can detect its emitted gravitational radiation.

**3.** We can observe the gravitational effect of the black hole on a visible star's orbit located near it. **correct**

**4.** We can observe the radiation from it.

**Explanation:**
There are various ways to *see* black holes. If it is the partner of a visible star, we can see its gravitational effect on the visible star's orbit. We could see its effect on light that passes close enough to be deflected but not close enough to be captured. We can see radiation emitted by matter as it is being sucked into a black hole (before it crosses the horizon to oblivion). In the future, perhaps, we will detect gravitational radiation emitted by black holes as they are being formed.

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**General Relativity 14**
**036 10.0 points**

Find the Schwarzschild radii of the Sun, Earth and a neutron star. The mass of the sun is $2 \times 10^{30}$ kg, the mass of the earth $5.98 \times 10^{24}$ kg, and the mass of the neutron star $1.67 \times 10^{-27}$ kg.

**1.** $$\begin{aligned} R_{sun} &= 296.444 \text{ m}, \\ R_{earth} &= 0.000886369 \text{ m}, \quad \text{and} \\ R_{neutron} &= 2.47531 \times 10^{-57} \text{ m}. \end{aligned}$$

**2.** $$\begin{aligned} R_{sun} &= 2964.44 \text{ m}, \\ R_{earth} &= 0.00886369 \text{ m}, \quad \text{and} \\ R_{neutron} &= 2.47531 \times 10^{-54} \text{ m}. \end{aligned}$$ **correct**

**3.** $$\begin{aligned} R_{sun} &= 2.96444 \text{ m}, \\ R_{earth} &= 8.86369 \times 10^{-6} \text{ m}, \quad \text{and} \\ R_{neutron} &= 2.47531 \times 10^{-57} \text{ m}. \end{aligned}$$

**4.** $$\begin{aligned} R_{sun} &= 296.444 \text{ m}, \\ R_{earth} &= 8.86369 \times 10^{-5} \text{ m}, \quad \text{and} \\ R_{neutron} &= 2.47531 \times 10^{-57} \text{ m}. \end{aligned}$$

**Explanation:**

$$\begin{aligned} \text{Let :} \quad M_{sun} &= 2 \times 10^{30} \text{ kg}, \\ M_{earth} &= 5.98 \times 10^{24} \text{ kg}, \quad \text{and} \\ M_{neutron} &= 1.67 \times 10^{-27} \text{ kg}. \end{aligned}$$

For the Sun,

$$\begin{aligned} R_s &= \frac{2\,G\,M}{c^2} \\ &= \frac{2\,(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)}{(3 \times 10^8 \text{ m/s})^2} \\ &\quad \times (2 \times 10^{30} \text{ kg}) \\ &= \boxed{2964.44 \text{ m}}, \end{aligned}$$

for the Earth,

$$\begin{aligned} R_e &= \frac{2\,G\,M}{c^2} \\ &= \frac{2\,(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)}{(3 \times 10^8 \text{ m/s})^2} \\ &\quad \times (5.98 \times 10^{24} \text{ kg}) \\ &= \boxed{0.00886369 \text{ m}} \end{aligned}$$

and for the neutron star,

$$\begin{aligned} R_n &= \frac{2\,G\,M}{c^2} \\ &= \frac{2\,(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)}{(3 \times 10^8 \text{ m/s})^2} \\ &\quad \times (1.67 \times 10^{-27} \text{ kg}) \\ &= \boxed{2.47531 \times 10^{-54} \text{ m}}. \end{aligned}$$