

X1.1

309

PHYS-309(2) (Kaldon-21722)
WMU - Winter 2000
Exam 0 - 000,000 points

Name _____

Book Title _____

5/13/1999•Rev.2

**State Any Assumptions You Need To Make – Show All Work – Circle Any Final Answers
Use Your Time Wisely – Work on What You Can – Be Sure to Write Down Equations
Feel Free to Ask Any Questions**

For all problems, use $c = 2.998 \times 10^8 \text{ m/s}$.

The White Star Line Classically Welcomes You to The Maiden Voyage of RMS Titanic... (25,000 points)

1.) The *Relativistic Merchant Starship Titanic* ($m = 60.0 \times 10^6 \text{ kg}$) leaves Earth to travel to the star colony Atlantis. It accelerates initially at 30 gee 's, or 294.3 m/s^2 , with a constant force $F = 17.66 \times 10^9 \text{ N}$ until the ship reaches a speed of $0.900 c$. (a) Using classical non-relativistic equations, find the time it takes the ship to accelerate to its cruising speed.

(b) What is the final kinetic energy of the *Titanic*?

The engines have to supply the work that effects the change in kinetic energy from rest to cruising speed. They work the same way the Sun does – by fusing deuterium into helium ${}^2_1\text{H} + {}^2_1\text{H} \rightarrow {}^4_2\text{He}$. (c) Find the energy released by mass-to-energy conversion from making one helium. Then (d) find out how many of these reactions you need to get the K.E. in (b). 1 u converts to $931.5 \text{ MeV} = (931.5 \times 10^6) \times (1.609 \times 10^{-19} \text{ J}) = 1.499 \times 10^{-10} \text{ J}$.

hydrogen-2 2.014102 u

helium-4 4.002603 u

(e) The star colony Atlantis is located 35.7 light years from Earth. How long will it take the *Titanic* to get to its destination from the point of view of an observer on Earth? (Ignore the added time due to acceleration at the beginning and deceleration at the end of the trip. In this case it doesn't affect the answer much.)



The White Star Line Relativistically Welcomes You to The Maiden Voyage of RMS Titanic... (25,000 pts)

2.)[†] The *Relativistic Merchant Starship Titanic* ($m = 60.0 \times 10^6 \text{ kg}$) leaves Earth to travel to the star colony Atlantis. It accelerates initially at 30 gee 's, or 294.3 m/s^2 , with a constant force $F = 17.66 \times 10^9 \text{ N}$ until the ship reaches a speed of $0.900 c$. For a constant force, F , differentiating the relativistic momentum with respect to time gives us:

$$F = \frac{dp}{dt} = m \left(1 - \frac{v^2}{c^2} \right)^{-\frac{3}{2}} \frac{dv}{dt} \quad [\text{Serway } M\&M \text{ Problem 1.28}]. \quad \text{Integrating } F dt \text{ and } m\gamma^3 dv \text{ or } \dots$$

$$\int_0^{.900c} F dt = \int_0^{.900c} m \left(1 - \frac{v^2}{c^2} \right)^{-\frac{3}{2}} dv \text{ gives us an equation for the relativistic } v \text{ as a function of } t: \quad v = \frac{Fct}{\sqrt{(m^2 c^2 + F^2 t^2)}}$$

[This answer is consistent with the results of Problem 1.29c].

(a) Given that the final cruising speed of the *Titanic* is $.900c$, solve the equation for v for the time it takes for the ship to reach its cruising speed. *Dr. Phil assumes that this is the time in the Earth reference frame, since the ship is not accelerating in its reference frame, and that would be general relativity anyway!* How does this answer compare to the time in the previous problem? Is this reasonable?

(b) What is the final relativistic kinetic energy of the *Titanic*?

The engines have to supply the work that effects the change in kinetic energy from rest to cruising speed. They work the same way the Sun does – by fusing deuterium into helium ${}^2_1\text{H} + {}^2_1\text{H} \rightarrow {}^4_2\text{He}$. (c) Find out how many of these reactions you need to get the K.E. in (b). 1 u converts to $931.5 \text{ MeV} = (931.5 \times 10^6) \times (1.609 \times 10^{-19} \text{ J}) = 1.499 \times 10^{-10} \text{ J}$.

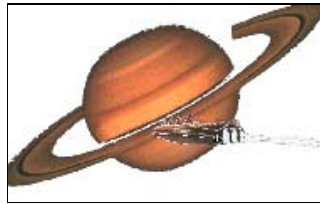
${}^2_1\text{H}$ hydrogen-2 2.014102 u

${}^4_2\text{He}$ helium-4 4.002603 u

(d) Each of these reactions requires two deuterium atoms (hydrogen-2). One mole of these reactions requires 4.03 grams of deuterium (0.00403 kg). What is the mass of the *fuel* needed to supply this kinetic energy? Compare it to the mass of the *Titanic*.

[†] NOTE: You may be able to use some of the results of the previous classical problem to find values here.

(e) The star colony Atlantis is located 35.7 light years from Earth. How long will it take the *Titanic* to get to its destination from the point of view of a passenger on the ship? (Ignore the added time due to acceleration at the beginning and deceleration at the end of the trip. In this case it doesn't affect the answer much.)



“Collision Alert! Collision Alert!” (25,000 points)

3.) Suppose there are particles called *bluons*. Each bluon has a mass of 1.25×10^{-25} kg. One of these bluons is at rest; the other is moving at $\gamma = 10.0$. (a) How fast is the moving bluon going?

(b) Find the total relativistic momentum of these two bluons.

(c) The two bluons collide and stick together. Find the relativistic momentum of the stuck-together bluons. *Hint: Think obvious.*

(d) Find the new speed v of the stuck-together bluons. *Note: v appears in two places in the relativistic momentum equation.*

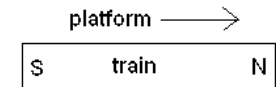
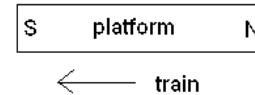
(e) The relativistic quantity $E^2 - p^2c^2$ is invariant in any transformation. Using the definitions of E and p , show algebraically that $E^2 - p^2c^2 = m^2c^4$.

“All Aboard!” (25,000 points)

4.) Amtrak has decided to get into the Modern Physics era, with a new train that travels at 89.1% the speed of light. The twenty cars of the train are 598 meters long. The platforms along this train line are exactly the same length. This train from New York to Washington doesn't stop in Princeton Junction NJ. Jimmy is standing on the platform in Princeton Junction. (a) Calculate how long the train appears to Jimmy on the platform...

and (b) how long the platform appears to Carol, the train's engineer.

Illustrate, with small rectangular boxes, the following points from both (c) Jimmy's and (d) Carol's P.O.V.: (I) When the front (S) end of the train passes the North end of the platform; (II) when the front (S) end of the train passes the South end of the platform; (III) When the rear (N) end of the train passes the North end of the platform; (IV) when the rear (N) end of the train passes the South end of the platform. Label each box with its Roman Numeral.



(e) Does simultaneity hold between parts (c) and (d)? *Briefly* explain why or why not.