# SPH4U
# UNIVERSITY PHYSICS

REVOLUTIONS IN MODERN PHYSICS: ...

☞ Mass Increase
(P.~)

## Mass Increase

*The fundamental quantities of mechanics are time, length, and mass. Both time and length have been shown to be relativistic; that is, their measured value depends on the frame of reference from which they are viewed. But what about mass? Using a derivation based on the Newtonian concept of conservation of momentum, Einstein was able to show that the mass of an object also changes with its speed, according to the equation:*

$$m_m = \frac{m_s}{\sqrt{1 - \frac{v^2}{c^2}}}$$

*where $m_s$ is the **proper** or **rest mass** and $m_m$ is the **relativistic mass**.*



## Mass Increase

**PROPER/REST MASS ($m_s$)**

- the mass of an object as measured by an observer who is stationary relative to the object

**RELATIVISTIC MASS ($m_m$)**

- the mass of an object as measured by an observer who is moving with speed v relative to the object

## Mass Increase

**MASS INCREASE**

- the increase in the mass of an object in one FOR that is moving relative to an observer in another FOR ($m_m \geq m_s$ )

$$m_m = \frac{m_s}{\sqrt{1 - \frac{v^2}{c^2}}}$$

where $m_m$ is the relativistic mass of the object (kg)

$m_s$ is the proper or rest mass of the object (kg)



## Mass Increase

***NOTE!***

*This equation predicts that no object can be accelerated to c. For example, as* ***v → c*** *then* ***1 – v²/c² → 0*** *and* ***m → ∞*** *(which is impossible).*

$$m_m = \frac{m_s}{\sqrt{1 - \frac{v^2}{c^2}}}$$

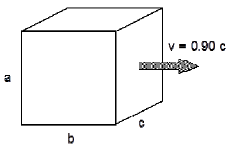


## Mass Increase

**PRACTICE**

1. A cube of aluminum 1.00 m x 1.00 m x 1.00 m is moving at 0.90c, as shown. The rest density of aluminum is 2.70 x $10^3$ kg/$m^3$.
   (a) Which of its three dimensions, a, b, or c, is affected by its motion?

(a) b

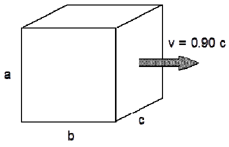


## Mass Increase

**PRACTICE**

1. A cube of aluminum 1.00 m x 1.00 m x 1.00 m is moving at 0.90c, as shown. The rest density of aluminum is 2.70 x $10^3$ kg/$m^3$.
   (b) Calculate its relativistic volume.

   (b) $V_m$ = 0.436 $m^3$



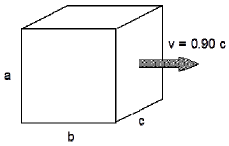



## Mass Increase

**PRACTICE**

1. A cube of aluminum 1.00 m x 1.00 m x 1.00 m is moving at 0.90c, as shown. The rest density of aluminum is 2.70 x $10^3$ kg/$m^3$.
   (c) Calculate its relativistic mass.

   (c) $m_m$ = 6.19 x $10^3$ kg



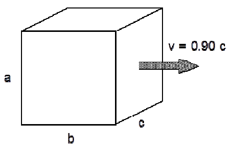



## Mass Increase

**PRACTICE**

1. A cube of aluminum 1.00 m x 1.00 m x 1.00 m is moving at 0.90c, as shown. The rest density of aluminum is 2.70 x $10^3$ kg/$m^3$.
   (d) What is its density at v = 0.90c?

   (d) $d_m$ = 1.42 x $10^4$ kg/$m^3$



## Mass Increase

**PRACTICE**

2. An electron has a rest mass of 9.11 x $10^{-31}$ kg. In a detector, it behaves as if it has a mass of 12.55 x $10^{-31}$ kg.
   (a) Derive an expression for v in terms of c, $m_s$, and $m_m$.

   (a) $v = c\sqrt{1 - \left(\frac{m_s}{m_m}\right)^2}$

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## Mass Increase

**PRACTICE**

2. An electron has a rest mass of 9.11 x $10^{-31}$ kg. In a detector, it behaves as if it has a mass of 12.55 x $10^{-31}$ kg.
   (b) How fast is that electron moving relative to the detector?

   (b) v = 2.06 x $10^8$ m/s

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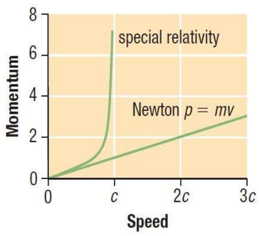
## Relativistic Momentum

***NOTE!***

*When an object's speed is small compared with the speed of light, Newtonian momentum gives a linear relation between p and v. By contrast, the **relativistic momentum** – the momentum of objects moving at speeds near the speed of light – becomes extremely large as the object's speed approaches c.*

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## The Universal Speed Limit

*Time dilation, length contraction, simultaneity, mass increase and relativistic momentum all involve the expression:*

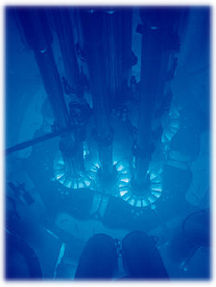
$$\sqrt{1-\frac{v^2}{c^2}}$$

*Since times, lengths, and masses are measurements, they must be represented by real numbers, so the value under the square root must be a positive number. For this to be true,* $v^2/c^2 < 1$ *which implies that* $v < c$*. Therefore, an object's speed must be less than the speed of light.*



## The Universal Speed Limit

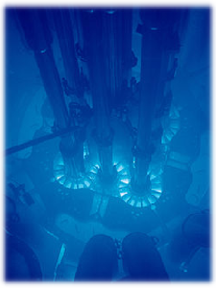
*This speed limit applies only to material objects. Obviously, light can travel at the speed of light. Also, once a light pulse has been slowed down by passing into a medium such as water, objects can travel faster through that medium than can the pulse.*





## The Universal Speed Limit

*For example, the blue glow (called "**Cerenkov radiation**") emanating from water in which radioactive material is being stored is created by high-speed electrons (beta particles) that are travelling through the water faster than the speed of light through water. This phenomenon is sometime compared to a sonic boom, in which particles (in the form of a jet airplane) are travelling faster than the speed of sound in air.*



## The Universal Speed Limit

**THE UNIVERSAL SPEED LIMIT ($v \ngtr c$)**

- in a vacuum (i.e. space) no object with a rest mass greater than zero can move as fast as, or faster than, c
- only applies to material objects since light travels at the speed of light
- the speed of light is the same for all observers (i.e. $c = 3.00 \times 10^8$ m/s)

**NOTE!**
Some objects can travel faster than light through a material medium such as water (i.e. Cerenkov radiation).



## The Universal Speed Limit

**PRACTICE**

3. How would our lives be affected if the speed of light, the ultimate speed possible, were 100 km/h, or about 28 m/s?

   answers will vary



## The Universal Speed Limit – DYK?

*Einstein's equations allow a particle to travel faster than light if it was already travelling faster than light when it was created. For such particles, called "**tachyons**," the speed of light represents the slowest speed limit. Although the equations say that tachyons can exist, there is no evidence that they do. In fact, no one knows how they would interact with normal matter.*

## Activity: Analyzing … (Inv.11.2.1/P.604)

**BACKGROUND**

In this activity you will determine the relativistic effects for a rocket moivng at different speeds relative to a stationary object.

**INSTRUCTIONS**

A. Follow procedure steps 1 to 8 but where it asks for relativistic momentum replace it with relativistic mass.

B. Answer the following:
   - procedure question 9 (3 scenarios)
   - analysis questions (b), (c), (d), (i)