Wrocław University of Science and Technology

Physics

JZL1001913C

summer semester

2020/2021

Wednesday, 18:20 - 19:50

Friday, 18:20 - 19:50

virtual room (ZOOM)

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room 213, building L-1

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Outline

- Introduction - Physics rules the world
- Motion phenomena - Kinematics
- Motion phenomena - Dynamics
- Rotational motion
- Harmonic motion
- Gravitational field
- **Relativistic phenomena**
- Basics of Thermodynamics
- Principles of Thermodynamics
- Kinetic theory of matter
- Electrostatics
- Electric current
- Magnetic field
- Vibrations and electromagnetic waves
- Optics
- Quantum nature of radiation
- Nuclear Physics

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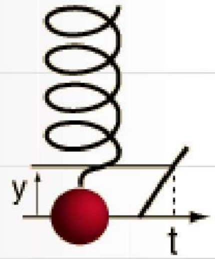
Harmonic motion - rewiev

Term	Meaning
Oscillatory motion	Repeated back and forth movement over the same path about an equilibrium position, such as a mass on a spring or pendulum.
Restoring force	A force acting opposite to displacement to bring the system back to equilibrium, which is its rest position. The force magnitude depends only on displacement, such as in Hooke's law.
Simple harmonic motion (SHM)	Oscillatory motion where the net force on the system is a restoring force.



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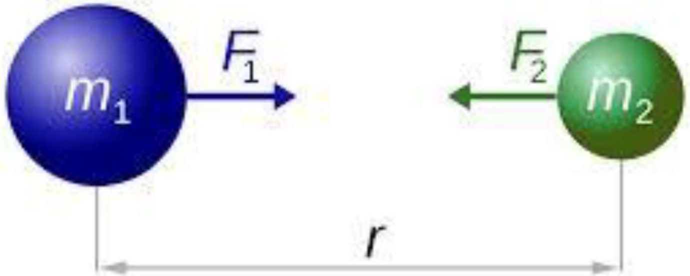
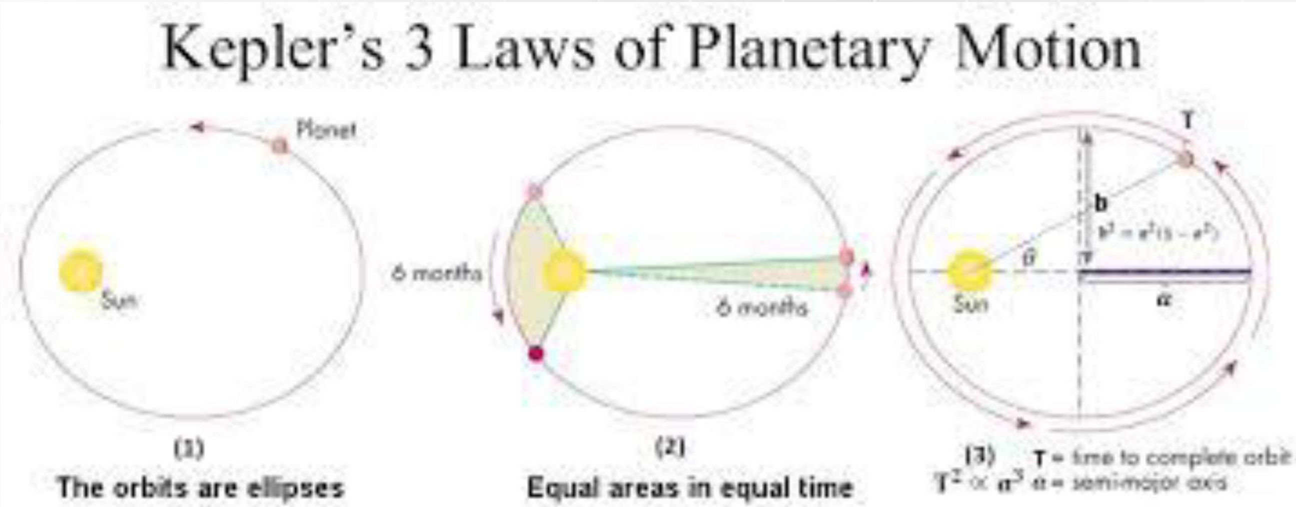
Gravitational field - review



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

$$g = G\frac{M}{r^2}$$

$$G = 6.674 \times 10^{-11}\,\frac{\mathrm{N}\cdot\mathrm{m}^2}{\mathrm{kg}^2}$$



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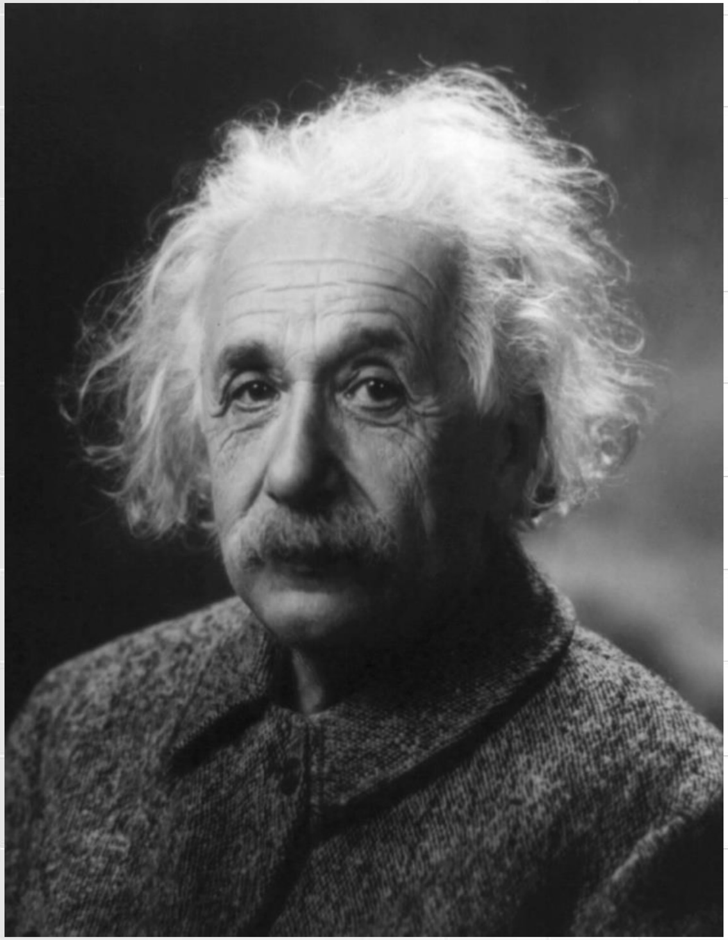
Relativistic phenomena

Have you ever looked up at the night sky and dreamed of traveling to other planets in faraway star systems? Would there be other life forms? What would other worlds look like? You might imagine that such an amazing trip would be possible if we could just travel fast enough, but you will read in this chapter why this is not true. In 1905 Albert Einstein developed the theory of special relativity. This theory explains the limit on an object's speed and describes the consequences.

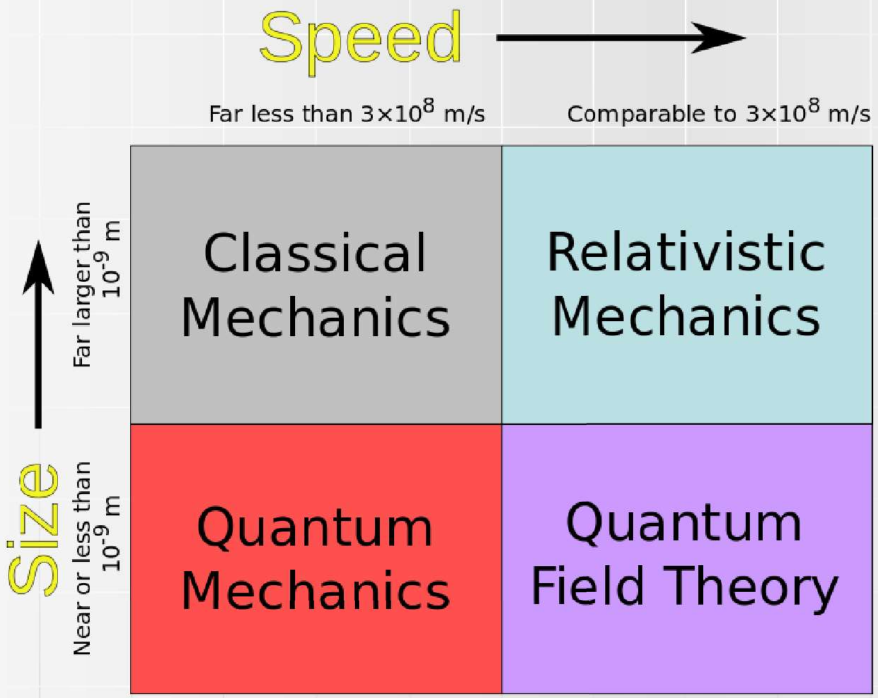
Relativity is the study of how different observers measure the same event.



Albert Einstein (1879–1955)

Limitations

It is important to note that although classical mechanics, in general, and classical relativity, in particular, are limited, they are extremely good approximations for large, slow-moving objects. Otherwise, we could not use classical physics to launch satellites or build bridges. In the classical limit (objects larger than submicroscopic and moving slower than about 1% of the speed of light), relativistic mechanics becomes the same as classical mechanics.



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Einstein's First Postulate

The first postulate upon which Einstein based the theory of special relativity relates to reference frames. All velocities are measured relative to some frame of reference. For example, a car's motion is measured relative to its starting point or the road it is moving over, a projectile's motion is measured relative to the surface it was launched from, and a planet's orbit is measured relative to the star it is orbiting around. The simplest frames of reference are those that are not accelerated and are not rotating. Newton's first law, the law of inertia, holds exactly in such a frame.

INERTIAL REFERENCE FRAME

An **inertial frame of reference** is a reference frame in which a body at rest remains at rest and a body in motion moves at a constant speed in a straight line unless acted on by an outside force.

As with many fundamental statements, there is more to this postulate than meets the eye. The laws of physics include only those that satisfy this postulate. We shall find that the definitions of relativistic momentum and energy must be altered to fit. Another outcome of this postulate is the famous equation $E=mc^2$

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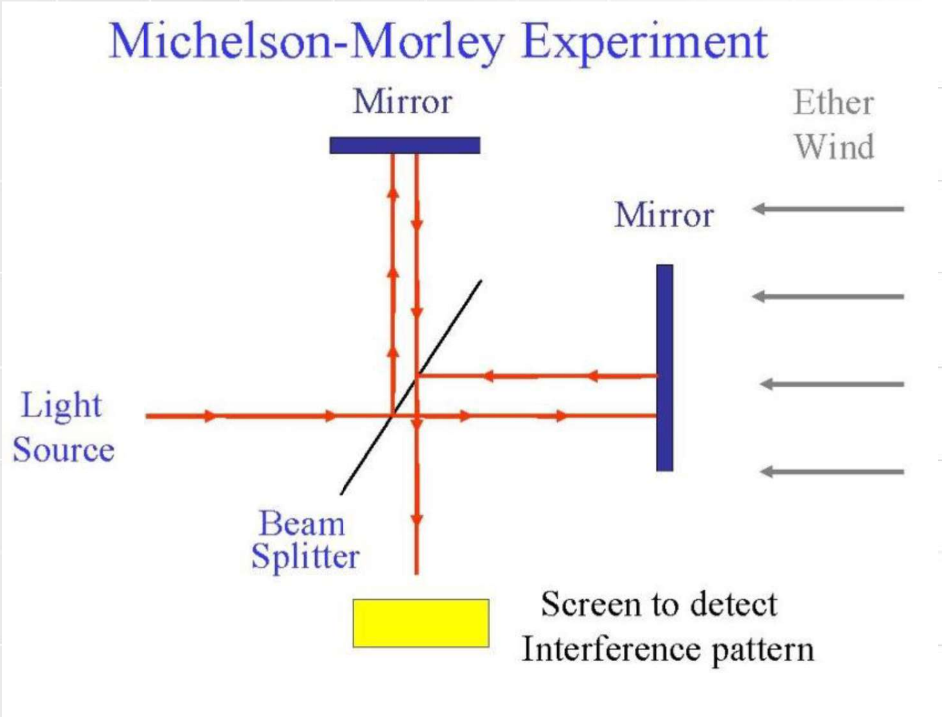
Michelson-Morley Experiment

MICHELSON-MORLEY EXPERIMENT

The **Michelson-Morley experiment** demonstrated that the speed of light in a vacuum is independent of the motion of the Earth about the Sun.

Investigations such as Young's double slit experiment in the early-1800s had convincingly demonstrated that light is a wave. Many types of waves were known, and all travelled in some medium. Scientists therefore assumed that a medium carried light, even in a vacuum, and light travelled at a speed c relative to that medium. Starting in the mid-1880s, the American physicist A. A. Michelson, later aided by E. W. Morley, made a series of direct measurements of the speed of light. The results of their measurements were startling.



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Einstein's Second Postulate

SECOND POSTULATE OF SPECIAL RELATIVITY

The speed of light c is a constant, independent of the relative motion of the source.

The eventual conclusion derived from this result is that light, unlike mechanical waves such as sound, does not need a medium to carry it. Furthermore, the Michelson-Morley results implied that the speed of light c is independent of the motion of the source relative to the observer. That is, everyone observes light to move at speed c regardless of how they move relative to the source or one another. For a number of years, many scientists tried unsuccessfully to explain these results and still retain the general applicability of Newton's laws.

MISCONCEPTION ALERT: CONSTANCY OF THE SPEED OF LIGHT

The speed of light is a constant $c = 3.00 \times 10^8\ \mathrm{m/s}$ *in a vacuum*. If you remember the effect of the index of refraction from The Law of Refraction, the speed of light is lower in matter.

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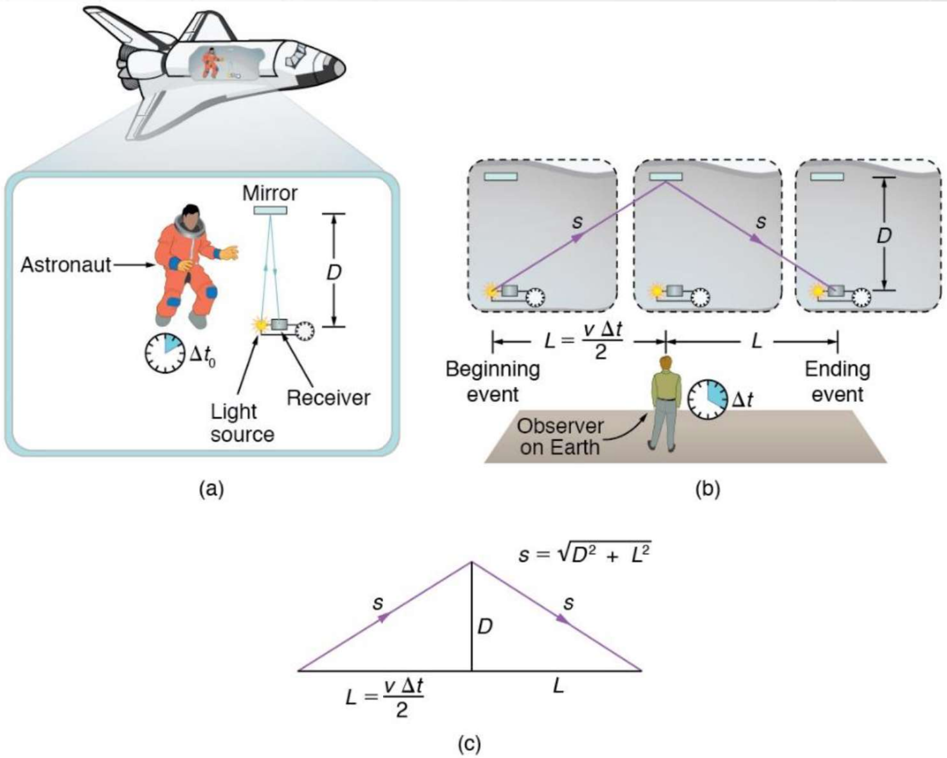
Time Dilation



$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma \Delta t_0$$

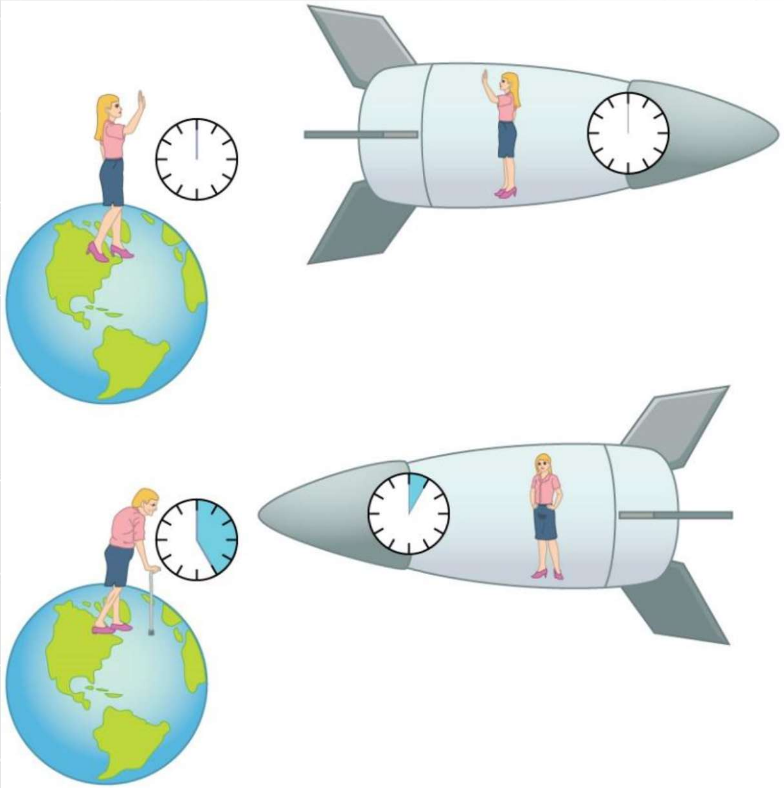
$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

TIME DILATION

Time dilation is the phenomenon of time passing slower for an observer who is moving relative to another observer.

The Twin Paradox

As with all paradoxes, the premise is faulty and leads to contradictory conclusions. In fact, the astronaut's motion is significantly different from that of the Earth-bound twin. The astronaut accelerates to a high velocity and then decelerates to view the star system. To return to the Earth, she again accelerates and decelerates. The Earth-bound twin does not experience these accelerations. So the situation is not symmetric, and it is not correct to claim that the astronaut will observe the same effects as her Earth-bound twin. If you use special relativity to examine the twin paradox, you must keep in mind that the theory is expressly based on inertial frames, which by definition are not accelerated or rotating. Einstein developed general relativity to deal with accelerated frames and with gravity, a prime source of acceleration. You can also use general relativity to address the twin paradox and, according to general relativity, the astronaut will age less.



The twin paradox asks why the traveling twin ages less than the Earth-bound twin. That is the prediction we obtain if we consider the Earth-bound twin's frame. In the astronaut's frame, however, the Earth is moving and time runs slower there. Who is correct?

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Proper Length

One thing all observers agree upon is relative speed. Even though clocks measure different elapsed times for the same process, they still agree that relative speed, which is distance divided by elapsed time, is the same. This implies that distance, too, depends on the observer's relative motion. If two observers see different times, then they must also see different distances for relative speed to be the same to each of them.

PROPER LENGTH

Proper length L_0 is the distance between two points measured by an observer who is at rest relative to both of the points.

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Length Contraction

LENGTH CONTRACTION

Length contraction L is the shortening of the measured length of an object moving relative to the observer's frame.

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$

If we measure the length of anything moving relative to our frame, we find its length L to be smaller than the proper length L_0 that would be measured if the object were stationary. For example, in the muon's reference frame, the distance between the points where it was produced and where it decayed is shorter. Those points are fixed relative to the Earth but moving relative to the muon. Clouds and other objects are also contracted along the direction of motion in the muon's reference frame.

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Mass in special relativity

The word *mass* has two meanings in special relativity: rest mass or invariant mass is an invariant quantity which is the same for all observers in all reference frames, while relativistic mass is dependent on the velocity of the observer. According to the concept of mass–energy equivalence, the rest mass and relativistic mass are equivalent to the rest energy and total energy of the body, respectively. The term *relativistic mass* tends not to be used in particle and nuclear physics and is often avoided by writers on special relativity, in favor of using the body's total energy. In contrast, *rest mass* is usually preferred over *rest energy*. The measurable inertia and gravitational attraction of a body in a given frame of reference is determined by its relativistic mass, not merely its rest mass. For example, light has zero rest mass but contributes to the inertia (and weight in a gravitational field) of any system containing it.

Mass of a body at rest

$$m_0 = \frac{E_0}{c^2}$$

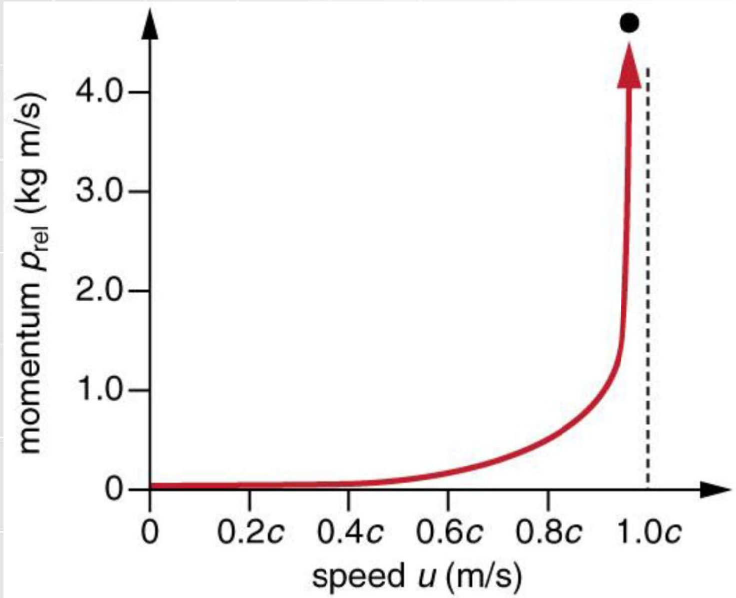
Relativistic momentum

Relativistic momentum p is classical momentum multiplied by the relativistic factor γ.

$\mathrm{p} = \gamma m v,$

where m is the rest mass of the object, v is its velocity relative to an observer, and the relativistic factor $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

Relativistic momentum approaches infinity as the velocity of an object approaches the speed of light.



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Total Energy and Rest Energy

Total energy E is defined to be

$$E = \gamma mc^2,$$

where m is mass, c is the speed of light, $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$, and v is the velocity of the mass relative to an observer. There are many aspects of the total energy E that we will discuss—among them are how kinetic and potential energies are included in E, and how E is related to relativistic momentum. But first, note that at rest, total energy is not zero. Rather, when $v=0$, we have $\gamma=1$, and an object has rest energy.

Rest energy is $E_0=mc^2$.

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Kinetic Energy

Kinetic energy is energy of motion. Classically, kinetic energy has the familiar expression $\frac{mv^2}{2}$. The relativistic expression for kinetic energy is obtained from the work-energy theorem. This theorem states that the net work on a system goes into kinetic energy. If our system starts from rest, then the work-energy theorem is

$W_{net}=E_{kin}$.

Relativistically, at rest we have rest energy $E_0=mc^2$. The work increases this to the total energy $E=\gamma mc^2$. Thus,

$W_{net}=E-E0=\gamma mc^2-mc^2=(\gamma-1)mc^2$.

Relativistically, we have $W_{net}=E_{kin\ rel}$.

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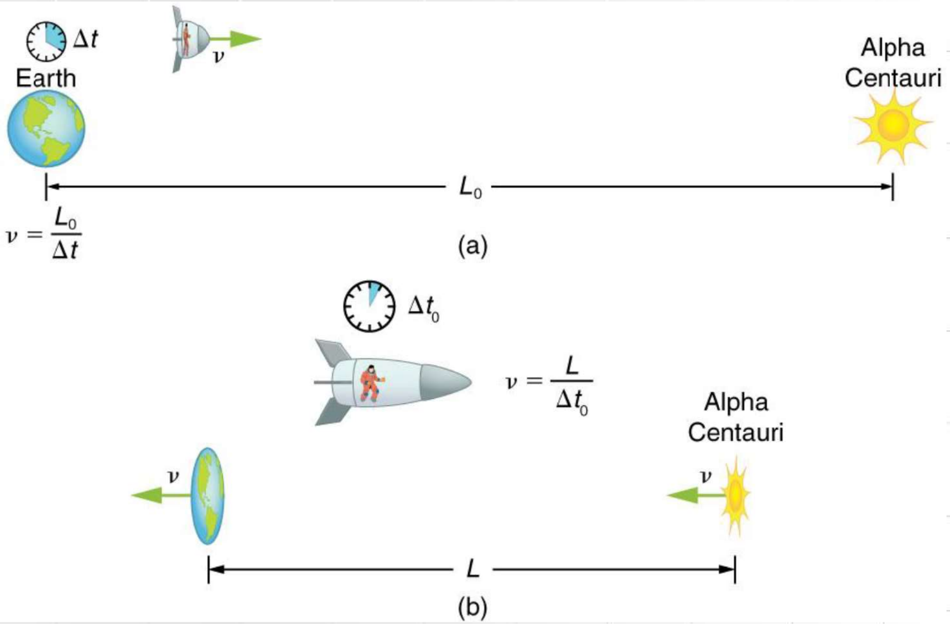
Additional materials

Lectures:
https://openstax.org/books/college-physics/pages/28-introduction-to-special-relativity

Videos:
https://www.khanacademy.org/science/physics/special-relativity

Motion phenomena – Relativistic phenomena

All right. So if you go to our website today, you will find I've assigned some problems and you should try to do them. They apply to this chapter. Then next week we'll do anothers problems connected with Basics of Thermodynamics.



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Quizz

Kahoot link:
https://kahoot.it/challenge/06839625?challenge-id=459c69ba-0699-474d-ae7d-12916780bd23_1616858954560

Deadline: 7th April 2021, 18:00