SUPERCHARGED SCIENCE

Unit 7: Astrophysics

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Appropriate for Grades:
Lesson 1 (4-12), Lesson 2 (K-12), Lesson 3 (6-12)
Duration: 6-20 hours, depending on how many activities you do!

Is time travel into the future possible? Are there really such bizarre objects that warp space and freeze time? What about wormholes and tunneling - are those possible? You bet! We're going to take a sneak peek at the laws of physics that govern these and more in our adventure through relativity.

Some of the activities and experiments for this unit are in your mind, the same way Albert Einstein did. Many people think that relativity (and quantum physics) is way too hard to comprehend. In fact, it doesn't take an Einstein to understand these concepts at all. In fact, you already know about special relativity in your everyday life experience.

Astrophysics combines our knowledge of light, chemical reactions, atoms, energy, and physical motion all into one. The things we're going to study in this unit borders on sci-fi weird, but I assure you it's all the same stuff real scientists are studying. This unit is broken into three completely separate sections that you can to in any order. Some are easy-and-fun and others are mind-bending-hard. If you feel like you're getting a little lost, simply jump over to the experiments and just have fun.

Table of Contents

Materials for Experiments

How many of these items do you already have? We've tried to keep it simple for you by making the majority of the items things most people have within reach (both physically and budget-wise), so you can pick up these items next time you're at the grocery store.

NOTE: This material list is for the entire Experiment section online.

2 sheets of paper
Small rocks
String
Magnet (any size)
Pencil
Radio that tunes near 100 MHz (the one in your car is perfect)
Black construction paper
Marble
Wire coat hanger (without insulation)
Aluminum foil
Clean, empty pickle jar
Hot glue gun, scissors, tape

For Grades 9-12:
Clean, empty pickle jar (yes, another one)
Black felt
Small block of dry ice block (use gloves to handle very carefully)
Rubbing alcohol

Key Vocabulary

Lesson 1: Particle Physics

Alpha particles is two protons and two neutrons stuck together (also known as helium nuclei).

Antimatter counterparts have characteristics that are opposite from their companion particle. The antimatter component to the electron is called the positron. The positron has the same mass as the electron, but its charge is positive.

An **atom** is smallest bit of stable matter.

Beta particles are either electrons or positrons.

The **electromagnetic force** keeps the electrons from flying away from the nucleus. When a plus (the nucleus) and minus (the electron) charge get close together, tiny particles called photons pull the two together.

Zipping around the nucleus is the **electron**, which carries a negative electrical charge and very little mass. Electrons cannot be split apart.

Fission is where you split an atom apart and get smaller parts and a *lot* of energy. When this happens in nature, it's called **radioactivity**.

The **fundamental strong** force holds the quarks together inside the proton and neutron.

The **fusion** process smacks particles together, which results in a big release of energy. Fusion is taking place inside the sun.

Gamma particles, also called gamma rays, are actually electromagnetic radiation (photons) of very, very high frequency and energy - high enough to damage living tissue.

Itty bitty particles called **gluons** hold the quarks together so the atom doesn't fly apart.

There are six different types of **leptons** but only two of which are stable and show up in ordinary matter. The electron is a lepton.

Matter is anything that has mass. Another way to think about it is that matter is anything affected by gravity.

Neutrons are made from two down and one up quark. Neutrons carry no charge.

This force binds the protons and neutrons together and is carried by tiny particles called **pions**.

The number of **protons** inside the atom determines what type of element it is. Protons are made from two up and one down quark. Protons carry a positive charge.

Quarks make up the nucleus of the atom. They are subatomic particles that you can arrange in certain ways to get protons and neutrons.

The **residual strong force** is the glue that sticks the nucleus of an atom together, and is one of the strongest force we've found (on its own scale).

Key Vocabulary

Lesson 2: Astronomy

Black holes are the leftovers of a BIG supernova. When a star explodes, it collapses down into a white dwarf or a neutron star. However, if the star is large enough, there is nothing to keep it from collapsing, so it continues to collapse forever. It becomes so small and dense that the gravitational pull is so great that light itself can't escape.

Galaxies are stars that are pulled and held together by gravity.

Globular clusters are massive groups of stars held together by gravity, using housing between tens of thousands to millions of stars (think New York City).

Gravitational lensing is one way we can "see" a black hole. When light leaves a star, it continues in a straight line until yanked on by the gravity of a black hole, which bends the light and change its course and shows up as streaks or multiple, distorted images on your photograph.

The **Kuiper Belt** is an icy region that extends from just beyond Neptune (from 3.7 billion miles to 7.4 billion miles from the sun). This is where most comets and asteroids from our solar system hang out.

Neutron stars with HUGE magnetic fields are known as **magnetars**.

Neutron stars are formed from stars that go supernova, but aren't big and fat enough to turn into a black hole.

The **Oort Cloud** lies just beyond the Kuiper belt, housing an estimated 1 trillion comets.

The visible surface of the sun is called the **photosphere**, and is made mostly of plasma (remember the plasma grape experiment?) that bubbles up hot and cold regions of gas.

Dying stars blow off shells of heated gas that glow in beautiful patterns called **planetary nebula**.

Pulsars are a type of neutron star that spins very fast, spews jets of high-energy x-ray particles out the poles, and has large magnetic fields.Our **solar system** includes **rocky terrestrial planets** (Mercury, Venus, Earth, and Mars), **gas giants** (Jupiter and Saturn), **ice giants** (Uranus and Neptune), and assorted chunks of ice and dust that make up various **comets** (dusty snowballs) and asteroids (chunks of rock).

Key Vocabulary

Lesson 3: Relativity

Absolute motion: Motion that exists, undeniably, without reference to anything else. The relativity principle denies the possibility of absolute motion.

Black hole: An object so small yet so massive that escape speed exceeds the speed of light. General relativity predicts the possibility of black holes, and modern astrophysics has essentially confirmed their existence.

Color force: The very strong force that acts between quarks, binding them together to form hadrons and mesons.

Dark matter: Matter in the cosmos that is undetectable because it doesn't glow. Dark matter, some of it in the form of as-yet-undiscovered exotic particles, is thought to comprise most of the universe.

Electromagnetic wave: A structure consisting of electric and magnetic fields in which each kind of field generates the other to keep the structure propagating through empty space at the speed of light, c. Electromagnetic waves include radio and TV signals, infrared radiation, visible light, ultraviolet light, x rays, and gamma rays.

Electroweak force: One of the three fundamental forces now identified, the electroweak force subsumes electromagnetism and the weak nuclear force.

Elsewhere: A region of spacetime that is neither past nor future. The elsewhere of a given event consists of those other events that cannot influence or be influenced by the given event—namely, those events that are far enough away in space that not even light can travel between them and the given event.

Escape speed: The speed needed to escape to infinitely great distance from a gravitating object. For Earth, escape speed from the surface is about 7 miles per second; for a black hole, escape speed exceeds the speed of light.

Ether: A hypothetical substance, proposed by nineteenth century physicists and thought to be the medium in which electromagnetic waves were disturbances.

Event horizon: A spherical surface surrounding a black hole and marking the "point of no return" from which nothing can escape.

Field: A way of describing interacting objects that avoids action at a distance. In the field view, one object creates a field that pervades space; a second object responds to the field in its immediate vicinity. Examples include the electric field, the magnetic field, and the gravitational field.

Frame of reference: A conceptual framework from which one can make observations. Specifying a frame of reference means specifying one's state of motion and the orientation of coordinate axes used to measure positions.

General theory of relativity: Einstein's generalization of special relativity that makes all observers, whatever their states of motion, essentially equivalent. Because of the equivalence principle, general relativity is necessarily a theory about gravity.

Gravitational lensing: An effect caused by the general relativistic bending of light, whereby light from a distant astrophysical object is bent by an intervening massive object to produce multiple and/or distorted images.

Gravitational time dilation: The slowing of time in regions of intense gravity (large spacetime curvature).

Gravitational waves: Literally, "ripples" in the fabric of spacetime. They propagate at the speed of light and result in transient distortions in space and time.

Gravity: According to Newton, an attractive force that acts between all matter in the universe. According to Einstein, a geometrical property of spacetime (spacetime curvature) that results in the straightest paths not being Euclidean straight lines.

Hadron: A "heavy" particle, made up of three quarks. Protons and neutrons are the most well known hadrons.

Length contraction: The phenomenon whereby an object or distance is longest in a reference frame in which the object or the endpoints of the distance are at rest. Also called the Lorentz contraction and Lorentz-Fitzgerald contraction.

Mass-energy equivalence: The statement, embodied in Einstein's equation $E=mc^2$, that matter and energy are interchangeable.

Maxwell's equations: The four equations that govern all electromagnetic phenomena described by classical physics. It was Maxwell in the 1860s who completed the full set of equations and went on to show how they predict the existence of electromagnetic waves. Maxwell's equations are fully consistent with special relativity.

Mechanics: The branch of physics dealing with the study of motion.

Michelson-Morley experiment: An 1880s experiment designed to detect Earth's motion through the ether. The experiment failed to detect such motion, paving the way for the abandonment of the ether concept and the advent of relativity.

Neutron star: An astrophysical object that arises at the end of the lifetime of certain massive stars. A typical neutron star has the mass of several Suns crammed into a ball with a diameter about that of a city.

Photoelectric effect: The ejection of electrons from a metal by the influence of light incident on the metal.

Photon: The quantum of electromagnetic radiation. For radiation of frequency f, the quantum of energy is $E=hf$.

Principle of Equivalence: The statement that the effects of gravity and acceleration are indistinguishable in a sufficiently small reference frame. The principle of equivalence is at the heart of general relativity's identification of gravity with the geometry of spacetime.

Principle of Galilean Relativity: The statement that the laws of motion are the same in all uniformly moving frames of reference; equivalently, such statements as "I am moving" or "I am at rest" are meaningless unless "moving" and "rest" are relative to some other object or reference frame.

Relativity principle: A statement that only relative motion is significant. The principle of Galilean relativity is a special case, applicable only to the laws of motion. Einstein's principle of special relativity covers all of physics but is limited to the case of uniform motion.

Spacetime: The four-dimensional continuum in which the events of the universe take place. According to relativity, spacetime breaks down into space and time in different ways for different observers.

Spacetime curvature: The geometrical property of spacetime that causes its geometry to differ from ordinary Euclidean geometry. The curvature is caused by the presence of massive objects, and other objects naturally follow the straightest possible paths in curved spacetime. This is the essence of general relativity's description of gravity.

Spacetime interval: A four-dimensional "distance" in spacetime. Unlike intervals of time or distance, which are different for observers in relative motion, the spacetime interval between two events has the same value for all observers.

Special theory of relativity: Einstein's statement that the laws of physics are the same for all observers in uniform motion.

Unit Description

Astrophysics combines our knowledge of light (electromagnetic radiation), chemical reactions, atoms, energy, and physical motion into one. The things we're going to study in this unit borders on sci-fi weird, but I assure you it's all the same stuff real scientists are studying. This unit is broken into two sections: easy-and-fun, and mind-bending-hard. If you feel like you're getting a little lost, simply jump over to the experiments and just have fun.

The first Lesson, *Particle Physics,* is mind-bending-hard, because we're going to deepen our understanding of the atom itself as we dig into the heart of matter. This will challenge your sense of reality and the only way you can make any sense of it is to leave your intuition behind. I've put it first not to drive you crazy, but to give you a background on what the second lesson (*Astronomy*) is all about. Like I said, if you feel that it gives you brain cramps, just skip it for now and jump right over to the fun stuff in *Astronomy*.

Note that the first lesson in *Particle Physics* is not essential to understanding the second lesson in *Astronomy*.

The second lesson, *Astronomy,* focuses on all the fun stuff about the universe and space exploration. We're going to look at the structures of stars, black holes, and even learn how gravity affects the orbits of planets by creating our own solar system and watching it go.

The third lesson, *Relativity,* is intended for advanced students who are thirsty for more and really want to get an overview of college-level physics and a start on how to think about relativity and Einstein's big ideas. The experiments and activities for this section are purely mental exercises and can be found in the last section: *Exercises for Lesson 3.* This lesson is not required for any other unit, but rather included as an appetizer for what awaits you in a career in science.

Objectives

Lesson 1: Particle Physics

Our study into particle physics is going to take us deep inside the structure of the atom. We're going to split it as far apart as it can go, so be prepared for complete weirdness that absolutely defies human intuition. Most of these particles don't exist outside of a laboratory, so it's not something you're going to run into very often. But it's still useful to know when trying to understand what you see looking through the eyepiece of a telescope.

We're also going to learn about light (radiation), and how different particles interact with each other. We'll cover matter, antimatter, dark matter, nuclear reactions, and more.

Here are the highlights for this unit for younger grades:

1. All matter is made up of some kind of atom.
2. Visible matter is made up of protons, neutrons, and electrons.
3. A proton has a positive charge, a neutron has no charge, and an electron has a negative charge.
4. When you split an atom or particle, it's called fission. It's how atomic bombs get their major amounts of energy. Fusion occurs when you squish atoms together. The sun creates its energy using fusion.
5. Most of an atom's mass is inside the nucleus.
6. Depending on the types of particles you smoosh or split, you get different amounts of energy.

Here are the highlights for this unit for older grades:

1. Quarks are small particles that you can arrange in different ways to build larger particles. The most common kind of quarks are 'up' and 'down'. Two 'up' quarks and one 'down' quark make one proton.
2. Tiny particles called pions stick protons and neutrons together. (There's no electromagnetic attraction between the positive proton and the neutral neutron.)

Pions are the carrier force for the residual strong force.

3. Tiny particles called gluons stick the quarks together inside a proton (and neutron). A gluon cannot exist outside of a proton, and is the carrier force for the strong force. The strong force is the strongest force on its own scale – it greatly weakens at distances larger than the nucleus of the atom.
4. The electromagnetic force uses a photon as 'carrier force' – the thing that binds the electron to the nucleus of the atom.
5. Most particles have anti-matter counterparts. The positron is the anti-matter companion to the electron.
6. There are hundreds and hundreds of particles in physics – we're only going to cover a few basics. Just enough to make your head spin.

Objectives

Lesson 2: Astronomy

Whew! After doing particle physics, this stuff is going to be easy… (well, at least until you get to the special relativity section for your high school student.)

Astronomers study celestial objects (stars, planets, moon, asteroids, comets, galaxies, etc) that exist outside our planet's atmosphere. Its the one field that combines most science, engineering and technology areas in one fell swoop. Astronomy is also one of the oldest sciences on the planet.

Early astronomers tracked the movement of the stars so accurately that in most cases, we've only made minor adjustments to their data. Although Galileo wasn't the first person to look through a telescope, he was the first to point it at the stars. Originally, astronomy was used as celestial navigation and involved with the making of calendars, but nowadays is mostly classified in the field called astrophysics.

There are different types of astronomers, some of which have never looked through a telescope. Amateur astronomers usually have smaller telescopes, and they don't get paid to do astronomy – they just do it for the love of it. Many amateur astronomers have discovered new objects based on their raw knowledge of the sky. Professional observational astronomers mostly use expensive scientific instruments to look through their massive telescopes. They spend a lot of time taking data and crunching numbers. Professional theoretical astronomers think up new ideas for getting the data to make sense. (Albert Einstein was theoretical – he hated to do experiments.)

Here are the highlights for this unit for younger grades:

1. Our solar system includes rocky terrestrial planets (Mercury, Venus, Earth, and Mars), gas giants (Jupiter and Saturn), ice giants (Uranus and Neptune), and assorted chunks of ice and

dust that make up various comets and asteroids.
2. Two planets have been reclassified after astronomers found out more information about their neighbors.
3. The sun uses nuclear reactions to generate its energy.
4. The Oort Cloud holds an estimated 1 trillion comets.
5. The Kuiper Belt holds the chunks of ice and dust, like comets and asteroids as well as larger objects like dwarf planets Eris and Pluto.
6. Galaxies are stars that are pulled and held together by gravity.
7. Globular clusters are massive groups of stars held together by gravity, using housing between tens of thousands to millions of stars.
8. Planetary nebulae are shells of gas and dust feathering away.
9. Neutron stars are formed from stars that go supernova, but aren't big and fat enough to turn into a black hole. Pulsars are spinning neutron stars with their poles aimed our way. Neutron stars with HUGE magnetic fields are known as magnetars.
10. Black holes are the leftovers of a BIG star explosion. There is nothing to keep it from collapsing, so it continues to collapse forever. It becomes so small and dense that the gravitational pull is so great that light itself can't escape.
11. Gravitational lensing occurs when black holes and other massive objects bend light.

Objectives

Lesson 3: Relativity

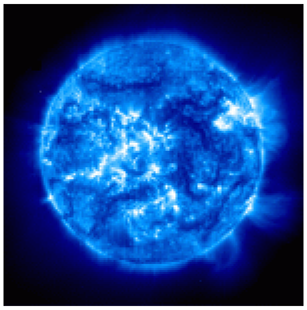
Here are the highlights for this lesson:

Relativity originally came from the questions asked about electricity and magnetism. Here's what we'll cover:

- Special Relativity states that the laws of physics are exactly the same for all observers in uniform motion.
- For special relativity "Special" means "unique case", which is constant speed and direction (uniform motion).
- The moment you accelerate or make a turn (change direction), you move into General Relativity.
- Special Relativity is not just a theory, it's a proven fact that has been more rigorously tested than all other theories in science.
- Time Dilation: Time does not pass at the same rate for all observers
- The speed of light is always constant for all observers.
- Different observers can see different things occur for the same event. There is no one preferred viewpoint.
- Lorentz Contraction: An object is longest in a frame which it is at rest and shorter in frames that it is moving.
- Gravitational Time Dilation: Time moves more slowly in regions of higher gravitational forces.
- A more massive object needs a greater force to achieve the same acceleration in direct proportion to its mass
- Principle of equivalence: Effects of gravity and acceleration are indistinguishable
- General theory of relativity states that laws of physics are the same in all reference frames
- Spacetime is curved by gravity
- Mass and energy cause spacetime to curve
- Law of motion: in the absence of forces, an object moves in the straightest possible path in curved spacetime
- Locally that path is always a straight line at uniform speed, but on larger scales it reflects the geometry of spacetime (not Euclidian geometry)

Textbook Reading

Lesson 1: Particle Physics



Matter is anything that has mass. Another way to think about it is that **matter is anything affected by gravity**. The matter you're familiar with is made up of atoms and ions, but that only makes up a small part of the matter in our universe. The matter in black holes is not necessarily made of the same stuff in your fridge.

A Overview of the Atom

All matter is made of some kind of particle. Visible matter (the chair, table, book, car, even you!) is made up of electrons and quarks. Quarks make up the nucleus of the atom. They are subatomic particles that you can arrange in certain ways to get protons and neutrons. Most of the mass is inside the atom's nucleus.

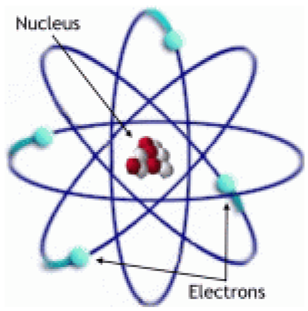
Zipping around the nucleus is the electron, which carries a negative electrical charge and very little mass. Atoms carry the same number of protons (positive charge) and electron (negative charge) so the charges cancel and the atom is usually neutral. If an atom loses or gains an electron, it becomes an ion and takes on a charge.

Free neutrons are generally unstable. It has to do with the way it's built, meaning how the quarks inside the neutron are arranged. If you could put a naked neutron by itself on a shelf, it wouldn't last more than fifteen minutes before it flipped and became a proton. Isn't science weird?

How to Turn Lead Into Gold

The number of protons inside the atom determines what type of element it is. For example, an atom with two protons in the core is a helium atom. An atom with eight protons is an oxygen atom. You can change the atom by adding or taking away protons. To turn lead (which has 82 protons) into gold (79 protons), you would take away three protons. It's that simple. (Or is it?)

What Keeps an Atom Together?



If you think about it, the nucleus of an atom (proton and neutron) really have no reason to stick together. The neutron doesn't have a charge, and the proton has a positive charge. And most nuclei have more than one proton, and positive-positive charges repel (think of trying to force two North sides of a magnet together). So what keeps the core together?

The strong force. Well, actually the *residual* strong force. This force is the glue that sticks the nucleus of an atom together, and is one of the strongest force we've found (on its own scale). This force binds the protons and neutrons together and is carried by tiny particles called pions. When you split apart these bonds, the energy has to go somewhere... which is why fission is such a powerful process (more on that later).

The **fundamental strong force holds the quarks together** inside the proton and neutron. Itty bitty particles called gluons hold the quarks together so the atom doesn't fly apart. This force is extremely strong - much stronger than the electromagnetic force. This force is also known as the color force (there is not any color involved - that is just the way it was named.)

The electromagnetic force keeps the electrons from flying away from the nucleus. When a plus (the nucleus) and minus (the electron) charge get close together, tiny particles called photons pull the two together.

What is Particle Physics?

Scientists love to smash things together and watch what happens. Galileo smacked bowling balls together, Newton was hit by an apple, and physicists today want to know what happens when you smack one tiny particle into another. By watching what happen when they collide and how they interact with each other, scientists can puzzle together what happens inside black holes, stars, and pulsars.

Antimatter

You know from science fiction that when matter and antimatter collide, they destroy each other and release a huge amount of energy. The question is, what *is* antimatter? And what makes it 'anti'?

Let's take the example of the electron. An electron is a small bit of matter with a negative charge and a certain amount of mass. The antimatter component to the electron is called the positron. The positron has the same mass as the electron, but its charge is positive. That's all there is to it. Antimatter counterparts have characteristics that are opposite from their companion particle.

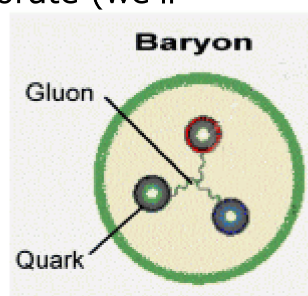
Dark Matter

When you look up at the stars tonight, notice how many bright stars you see. Is there more light or dark space in the night sky? Even though it seems that there's a lot of empty space out there, there is way more matter *inside* stars than anywhere else in our universe. All visible matter is made up of protons, neutrons, and electrons... but there are hundreds of other kinds of particles that make up matter as well.

This invisible mass is called dark matter, and some of it takes the form of MACHOs (massive compact halo objects) and WIMPs (weakly interacting massive particles). Scientists are still trying to figure out what they are and how they act. Most of these live only for a very short time (think less than a blink of an eye), so scientists have to be very fast at taking their data.

Surprise!

Matter and antimatter pairs are constantly popping in and out of existence in our universe. One minute, they don't exist, then next second *POP!* there they are... but then faster than you can blink, the pair smacks into each other and *POOF!* both are destroyed and give off a puff of energy. It's just one of the weird ways that the universe is wired. This is also the basis for how black holes evaporate (we'll talk about Hawking Radiation later).



What other particles are there?

Physicists gave these little bits of matter all sorts of odd names. Are you ready for these?

Here are the most common fundamental particles (meaning that you can't split it in half anymore - it's as small as it can get: leptons and quarks. There are six different types of leptons but only two of which are stable and show up in ordinary matter. There are also six different kinds (called 'flavors') of quarks, but only two can occur in ordinary matter ("up quark" and "down quark"). By the way, the person who named it 'quark' named it after his favorite type of cheese back in the day (quark cheese, anyone?).

There are several different composite particles (particles that have an internal structure - meaning that you can still split it in half): baryons, mesons, and positive pions. Baryons are larger particles containing quarks, mesons contain a quark and an antiquark, and a positive pion has one up quark and one anti-down quark. There are hundreds of different kinds of baryons and mesons.

The carrier particles are the ones that carry the force between the particles. Some of these we haven't really seen for ourselves - we're just guessing. They include: the gluon (glues together quarks inside a proton or neutron), the photon (carries the electromagnetic charge), the graviton (our best guess as to what causes gravity), and others.

Your head is probably about to explode, so I'll leave you with just one more thought - most of these particles also have an antimatter component... so there are quarks and anitquarks, protons and antiprotons, neutrons and antineutrons, neutrinos and antineutrinos... the list goes on and on! Remember, the positron has a positive charge while the electron has a negative charge. The antiproton has a negative charge and the proton has a positive charge. The antineutron still has no charge (like the neutron), but is made up of antiquarks instead of quarks.

Nuclear Fusion and Fission

In the 20th century, scientist figured out that the core of an atom can break apart or join together with others. If you split an atom (called fission), you get smaller parts and a whole lot of energy. When this happens in nature, it’s called radioactivity. Unstable atoms spontaneously break apart and release particles and energy.

Fusion is taking place inside the sun. The sun is not on fire, like a campfire or stove. So where does it get its energy from? The fusion process smacks particles together, which results in a big release of energy. The core of the sun is about one million degrees Celsius, which the surface temperature is a mere 15,000 degrees Celsius. The fusion process in the sun takes two naked protons (also known as a hydrogen nuclei) and smacks them together in a special sequence that results in the formation of helium. This complicated reaction is called the proton-proton chain, and occurs in all stars burning hydrogen in their core.

In chemistry, when you combine things together, you get different stuff out the other end. For example, when you mix together baking soda and vinegar, you get liquid water and sodium acetate precipitate in the cup, and carbon dioxide bubbles released into the atmosphere. When the core of a star fuses together in a supernova, it creates every element on the periodic table (yes, even gold!) and also spits out high-energy alpha, beta, and gamma particles.

Alpha particles were named long before we ever knew *what* they were. An alpha particle are two protons and two neutrons stuck together (also known as helium nuclei). Beta particles are either electrons or positrons. Gamma particles, also called gamma rays, are actually electromagnetic radiation (photons) of very, very high frequency and energy - high enough to damage living tissue. Fortunately, gamma ray bursts are rare and usually not pointed in our direction.

How Does a Nuclear Reactor Work?

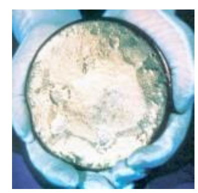
When people think of nuclear power, they often think of disaster-type scenes. Actually, power plants are very similar to coal-burning power plants. They both heat water into steam, which turn generators. The main difference between them is they way they heat the water. Some plants burn fossil fuels (like coal and oil), and nuclear plants use the energy from fission (splitting atoms apart) to heat water.

Remember when we talked when an atom spontaneously undergoes fission**,** it's called radioactivity? Uranium-235 is the perfect example of this kind of atom. U-235 decays naturally by spitting of an alpha particle or two neutrons and two protons bound together. However, U-235 is one of the few materials that can undergo fission both naturally and artificially, so it's a great choice for nuclear power plants. If a naked neutron zipping along by itself suddenly runs into the nucleus of a U-235 atom, the neutron gets absorbed by the core, which cases the atom to be unstable and split immediately.

Are Nuclear Weapons Different from Nuclear Power Plants?

Yes. Nuclear weapons allow the explosive energy in the atom to essentially run rampant, while power plants harness the atomic energy to heat water. The two types of nuclear weapons use energy from either fission (atomic bombs or A-bombs) or fusion (hydrogen bombs or H-bombs).

Atomic bombs get their explosive energy solely from the core of the atom. An atom by itself usually doesn't spontaneously split - you need to have a certain amount (called the critical mass) in order to start the fission process. In an atomic bomb, they separate a small chunk of material (usually plutonium or uranium) from the main lump so that the resulting lump mass is slightly *less* than the critical mass (so it doesn't explode before you want it to). The removed chunk is placed in a shotgun-looking device that will fire directly into sub-critical-mass lump when triggered.



Another way to get the reaction started is to detonate high-energy chemical reactions all around the lump of material, compressing it until it splits on its own.

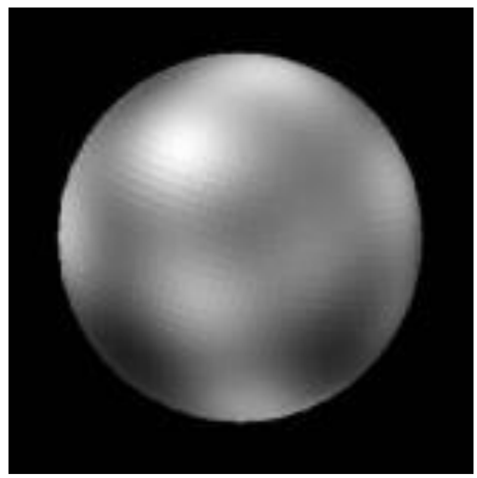
Textbook Reading

Lesson 2: Astronomy

The solar system is the place that is affected by the gravity our sun. Our solar system includes rocky terrestrial planets (Mercury, Venus, Earth, and Mars), gas giants (Jupiter and Saturn), ice giants (Uranus and Neptune), and assorted chunks of ice and dust that make up various comets and asteroids. The eight planets follow a near-circular orbit around the sun, and many have moons. We'll be going into detail about these objects during our hour-long teleclass, so we won't be spending time on it here. However, we will cover the huge number of comets, asteroids, and other objects follow their own path around the sun, many of which have yet to be discovered.

What Happened to Pluto?

Pluto was once considered one of the planets, but in recent years was demoted to 'dwarf planet' status. (This photo, by the way, is the ONLY picture we currently have of Pluto.) Many people figured it got whacked out of existence; while others thought we had discovered a larger planet X in its place. It turns out that neither are true. But before I talk about Pluto, let's go back in time to the discovery of another planet in our solar system, Ceres.



In 1801, Giuseppe Piazzi was looking in the asteroid belt region between Mars and Jupiter and was startled to find a large object there. He named it Ceres, and over the next several years, ten more 'planets' were discovered… then twenty, then fifty… and then a new definition of planet was defined, which moved all of these new 'planets' into the asteroid belt.

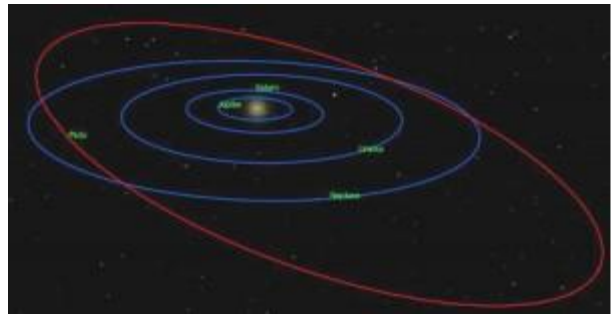
Back then, their observational equipment only allowed them to see large objects, and Ceres is the largest asteroid in the belt, so they naturally thought it was by itself and supposed it to be a planet, not a large rock amidst smaller ones.

Today, the same thing is happening with Pluto. Pluto is very small and far away, and it’s hard to see things that far and that small. But we keep trying, anyway!

Basically, astronomers found Pluto and named it a planet… then they found Charon, which is roughly half the size of Pluto, so we called it a moon. But then we discovered that Charon orbits a point that is between the Charon and Pluto, owing to the fact that Charon and Pluto are near the same size.

For comparison, the moon is 1/4 Earth's diameter, 1/50 Earth's volume, and 1/80 Earth's mass. Then we found two smaller objects (Hydra and Nix) that also orbit around the pair… making it four objects instead of the original one! But it gets worse, because then we found more objects beyond Pluto that were bigger… hundreds more!

So at the end of it, scientists had to redefine what it means to be a planet, and Pluto didn’t make the cut. But neither did the 700 other objects that we had in our line-up.



If you take a look at all the objects and ask yourself “Which one doesn’t belong?”, you’d find yourself looking hard at Pluto. It’s the only one on a seriously inclined orbit (shown in red), the only one with an elliptical orbit that crosses another planet’s orbit (Neptune's), and is extremely small compared to its neighbors. This is exactly what astronomers figured.

So Pluto was reclassified and the whole kit and caboodle was chunked as Kuiper Belt Objects (KBOs). This is the sort of thing that happens when you’re working in a new field, trying to make sense and define things as you go. Every so often, you learn new things and need to go back and readjust assumptions made in the past.

Our Sun

The sun holds 99% of the mass of our solar system. The sun’s equator takes about 25 days to rotate around once, but the poles take 34 days. You may have heard that the sun is a huge ball of burning gas. But the sun is not on fire, like a candle. You can't blow it out or reignite it. So, where does the energy come from?

The nuclear reactions deep in the core transforms 600 million tons per second of hydrogen into helium using a chemical processes called the proton-proton chain.

This gives off huge amounts of energy which gradually works its way from the 15 million-degree Celsius temperature core to the 15,000 degree Celsius surface. Once at the surface, it takes light only 8 minutes to travel the 93 million miles to reach earth. (So if the sun suddenly blinked out, we wouldn't know it for 8 minutes.)

The corona is hundreds of times hotter than the photosphere and extends for millions of miles outward. The only time you can see the corona is during an eclipse because the main part of the sun is so bright.

The visible surface of the sun is called the photosphere, and is made mostly of plasma (remember the grape experiment?) that bubbles up hot and cold regions of gas. When an area cools down, it becomes darker (called sunspots). Solar flares (massive explosions on the surface), sunspots, and loops are all related the sun's magnetic field. While scientists are still trying to figure this stuff out, here's the latest of what they do know...

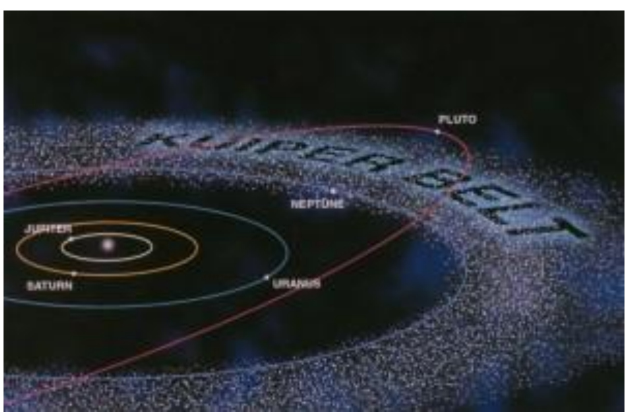
The sun is a large ball of really hot gas - which means there are lots of naked charged particles zipping around. And the sun also rotates, but the poles and the equator move and different speeds (don't forget – it's not a solid ball but more like a cloud of gas).

When charged particles move, they make magnetic fields (that's one of the basic laws of physics). And the different rotation rates allow the magnetic fields to 'wind up' and cause massive magnetic loops to eject from the surface, growing stronger and stronger until they wind up flipping the north and south poles of the sun (called 'solar maximum'). The poles flip every eleven years.

There have been several satellites specially created to observe the sun, including Ulysses (launched 1990, studied solar wind and magnetic fields at the poles), Yohkoh (1991-2001, studied x-rays and gamma radiation from solar flares), SOHO (launched 1995, studies interior and surface), and TRACE (launched 1998, studies the corona and magnetic field).

Kuiper Belt and Beyond

The Kuiper Belt is an icy region that extends from just beyond Neptune (from 3.7 billion miles to 7.4 billion miles from the sun). Most objects in this region take hundreds of years to orbit the sun from this distance. This is where most comets and asteroids from our solar system hang out. The largest object out there is Eris, but we're still finding new ones all the time.



Eris is the largest known dwarf planet (the other dwarfs are Ceres and Pluto), orbiting 10 billion miles away from the sun. It takes Eris 560 years to complete one trip around the sun. Sedna is the coldest object we've found in our solar system. It's a tiny rock (930 miles across) about 8.4 billion miles away from the sun, discovered in 2003. It would be like trying to spot a single grain of sand in California from the Moon.

Gerard Kuiper (1905-1973) is known as the father of planetary science for his discoveries of moons in the solar system as well as detecting atmospheres on Titan and Mars.

The Oort cloud lies just beyond the Kuiper belt, housing an estimated 1 trillion comets. The Oort cloud is so large that it occasionally gets stirred up by nearby stars (like Alpha-Centauri, our nearest neighbor). When this happens, the gravitational effect can either bump the comet's orbit toward our sun, or sling it forever out of our system toward other stars. Jan Oort (1900-1992) was one of the world's top astronomers who first figured out that our solar system was surrounded by a cloud of comets. He also figured out where the center of our galaxy is (in Sagittarius).

Galaxies

Stars like to live together in families. Galaxies are stars that are pulled and held together by gravity. Some galaxies are sparse while others are packed so dense you can't see through them. Galaxies also like to hang out with other galaxies (called galaxy clusters), but not all galaxies belong to clusters, and not all stars belong to a galaxy.

Active galaxies have very unusual behavior. Most galaxies have super-massive black holes in the center, many of which lie dormant. Scientists think active galaxies are the ones where the black hole is actively feeding on in-falling material. What scientists can detect are huge bursts of energy in the form of x-ray and gamma rays spewing up and out of the plane of the galaxy - a sure sign of a voracious black hole. There are several different types of active galaxies, including radio galaxies (edge-on view of galaxies emitting jets), quasars (3/4 view of the galaxy emitting jets), blazars (aligned so we're looking straight down into the black hole jet), and others. Our own galaxy, the Milky Way, has a super-massive black hole at its center, which is currently quiet and dormant.

Globular and Open Clusters

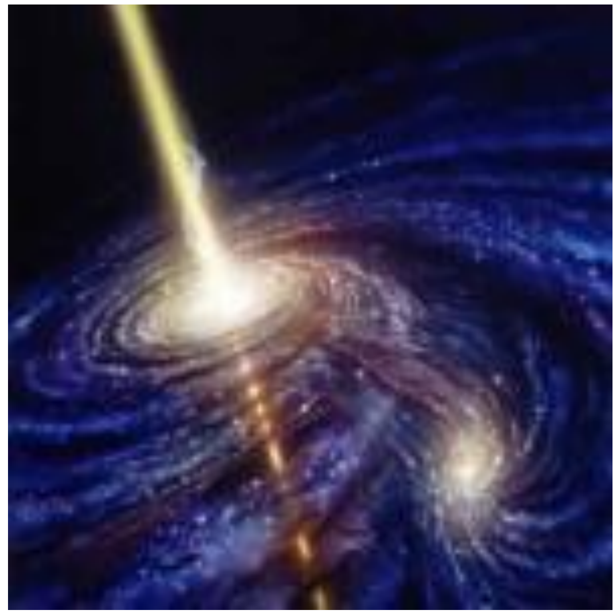
When you look up at the night sky, it seems like the pinpoints of light are each isolated from each other. When viewed through a telescope, however, single stars can actually transform into tens of millions of stars. Globular clusters are massive groups of stars held together by gravity, usually between tens of thousands to millions of stars (think New York City). Open clusters are made up of stars that all have the same chemical composition, but don’t usually stay together for long.

Planetary Nebulae

Dying stars blow off shells of heated gas that glow in beautiful patterns. William Hershel (1795) coined the term ‘planetary nebula’ because the ones he looked at through 18th century telescopes looked like planets. They actually have nothing to do with planets – they are shells of dust feathering away.

Neutron Stars and Pulsars

When a star uses up its fuel, the way it dies depends on how massive it was to begin with. Smaller stars simply fizzle out into white dwarfs, while larger stars can go supernova. A recent supernova explosion was SN 1987. The light from Supernova 1987A reached the Earth on February 23, 1987 and was close enough to see with a naked eye from the Southern Hemisphere.



Neutron stars are formed from stars that go supernova, but aren’t big and fat enough to turn into a black hole. When a star this size explodes, it blows off its outer layers of gases and the inner core collapses down and crushes the atoms together so much that protons and electrons fuse into neutrons. The neutrons are so densely packed together that the space between them is basically gone. Pick up a strand of your hair right now – feel how heavy it is? If this was made of neutron material, it would weigh the same as the empire state building.

As the neutron star forms, it starts to rotate and form huge magnetic fields. We already know that when you have magnetic fields, electrical fields are not far behind. Neutron stars can wind up spinning very fast, spewing jets of high-energy x-ray particles out the poles. When our telescopes detect the x-rays from a neutron star, we call it a pulsar.

Neutron stars with HUGE magnetic fields are known as magnetars, but because they were first modeled in 1992, not a lot is known about them. We currently know about only a handful of these, and thankfully none are near the Earth. To get a better sense of these things, compare the magnetic fields: the Earth registers at 1 gauss, Jupiter is 1,000 gauss, solar flares are 1,000 gauss, and a magnetars has magnetic fields that register 1,000,000,000,000,000 gauss.

Black Holes

Black holes are the leftovers of a BIG supernova. When a star explodes, it collapses down into a white dwarf or a neutron star. However, if the star is large enough, there is nothing to keep it from collapsing, so it continues to collapse forever. It becomes so small and dense that the gravitational pull is so great that light itself can't escape.

What would it be like to fall into a black hole? Well, there are two different perspectives. Imagine your friend Alice parked her spaceship a safe distance away, just outside the event horizon. She's not in any danger of being pulled in – she just wants to watch you go in.

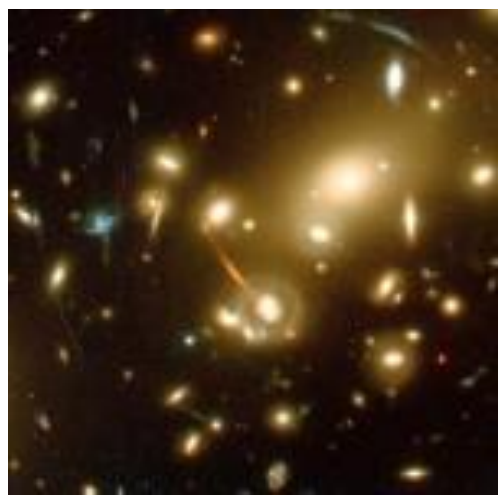
As you float toward to black hole, she sees you drift toward it, picking up speed as you get closer. She sees you going faster and faster, speeding up so that you're going near break-neck speed, and then you get close to the event horizon (the 'point of no return' – think about being in a boat going over Niagara Falls – there's a point that you can't escape going over no matter how hard you paddle). She sees you slow down as you approach the event horizon, turn redder and redder, and slowly fade away. She never actually sees you go in.

From your point of view, however, things went a little differently. First, you headed toward the black hole feet-first, and initially went slowly. As you got closer, your speed picked up faster and faster until the gravitational pull at your feet was different from the pull at your head, at which time you became 'spaghettified' (no kidding – that is the real astronomical term for this effect) where you were pulled into a super-thin, super-long string and finally shredded on the subatomic level.

So, how do you avoid such a fate? The only way you can detect a black hole is to look at what is happening around or because if it. If a star seems to be yanked about, but there's nothing there to do the gravitational pulling, you can bet it's a black hole. Stuff doesn't just fall straight into a black hole, either. When matter approaches the black hole, it stars to swirl around an accretion disk, which heats up the particles in the disk and lights up the disk so it's visible in the x-ray part of the spectrum (even though the black hole itself is not). You can also detect black holes by the way light is bent when passing by.

Gravity Bending Light

Gravitational lensing is one way we can "see" a black hole. When light leaves a star, it continues in a straight line until yanked on by the gravity of a massive object (like a galaxy or black hole). The gravity will bend the light and change its course, which can show up as streaks or multiple, distorted images on your film where they should be pinpoints of light (see the streaks in the photo?).



Textbook Reading

Lesson 3: Relativity

Space and Time

Most people use common sense when they interact with their world**.** They know that if they are traveling 60 mph and an oncoming car travels also at 60 mph, the impact will feel like 120 mph. But you'll have to leave all that behind as we step into the world of special relativity.

Problems with Newtonian Physics

In the late 19th century, a famous experiment by Michelson and Morely was conducted to detect the Earth's motion through the 'ether'. The 'ether' was something the scientists thought up to explain how electromagnetic waves traveled through space. Initially, they did not believe that light could travel through a vacuum like space. Today, we know that the ether does not exist and light really does travel through a vacuum.

The experiment went something like this: if we shine a beam of light in the same direction that the earth is rotating (along the equator), then the speed of the light can be added to the speed of the earth's rotation, and the two speeds will add and can be measured against a beam of light aimed toward the north pole (where the rotation speed does not factor into the light speed). This was a very plausible idea.

This about this: If you are traveling in a car at 60 mph, and you poke your head out the sunroof to toss a ball at 20 mph out of the car, how fast is the ball going?

Well, it depends. Imagine the car is passing a gas station right when you throw the ball.

If you toss the ball in the same direction that the car is traveling in, the ball speed will be seen by an observer standing at the gas station would be 80 mph.

If you toss the ball perpendicular to your line of travel (for instance, directly to the person at the gas station), then the ball speed is 60 mph in the forward direction and 20 mph in the sideways direction.

Notice that they don't add together! They are not supposed to. So, it was logical to expect that light would behave the same way.

Well, it didn't.

The light from both beams actually measured the same exact speed. It would be like your ball staying at the constant 60 mph no matter how hard you throw it.

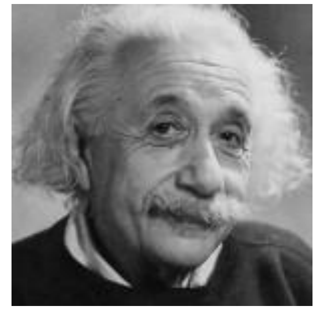
And scientists realized that something very odd was going on. It took decades before Einstein was able to come to the rescue with his ideas about relativity and spacetime.

Here's the short answer: It was discovered that the laws of Newtonian physics work fine when dealing with objects traveling at slow speeds. By slow I mean slow compared to the speed of light.

To be exact, Newtonian physics starts to break down with speeds greater than 10% of the speed of light, or 30,000 meters per second. For speeds faster than this, we have to worry about the effects of relativity.

Special Relativity

Albert Einstein in 1905 came up with an idea that shook the entire scientific field. At that time, there were two principles that everyone assumed were true, which Einstein rejected. The first idea he rejected was "every viewpoint is absolute".



Einstein said that there is no one right viewpoint. What does 'absolute viewpoint' mean?

It means that there is a unique and special point of view that's really the 'right' one, and all the other viewpoints are not valid for doing science experiments in.

For example, if you are playing tennis on a cruise ship traveling at constant steed in a straight line, does it matter which way you serve? Do you need to take into account the motion of the boat when you hit the ball?

No! It doesn't matter at all. You play the same game on a cruise ship as you would at the beach, at a park, or even on Venus (inside a dome so you can breathe and not be crushed by the atmosphere).

So what's the speed of the tens ball as you whack it toward the front of the ship?

It depends on your viewpoint (or frame of reference).

To you, you see only the speed of the ball. To an observer standing on the dock watching you as the boat passes by, they see a faster speed for the ball, because the speed of the ball is added to the speed of the ship. So which perspective is right?

They *both* are.

And this is what makes special relativity so ingenious!

Special relativity simply states that the laws of physics are valid for all observers in uniform motion.

All frames of reference (in uniform motion) are equally valid for doing physics experiments in and having the laws of physics hold true.

What if you're traveling at 600 mph? Are the laws of physics still working? Can you play tennis just the same on a plane at 600 mph as you would in a boat?

Yes, as long as the plane is moving in a straight line at constant speed.

You know this already, intuitively – let me show you how: have you ever tried to open a bag of peanuts on an airplane? Do they go flying everywhere because they are really going 600 mph, or do they act just like they would if they were at rest?

You know from experience that the peanuts are easy to get out of the bag – they act just as they would as if you weren't' moving at all. The laws of physics are the same for all observers in uniform motion.

If your boat enters a storm or the plane encounters turbulence, then the peanuts go flying everywhere, the tennis ball bounces in some odd direction, and you don't have uniform motion anymore. When this happens, you need to use a more complicated form of relativity to account for the acceleration, called General Relativity (which we'll get to later).

By the way, the word 'special' in Special Relativity simply means that this is a 'special case' in which the motion is uniform. There's nothing else special about it except the requirement that the motion must be in a straight line and at constant speed.

One of the predictions that comes out of this idea about all viewpoints being equal is that all electromagnetic waves, including light, travel with speed c (186,000 miles per second), *even though different observes may move relative to each other!*

Imagine you're standing at a gas station and you have a device that can measure the speed of light. It has a very fast clock inside that will measure how long it takes light to travel along the meter stick inside. Your friend drives by in a car at 70 mph with an identical device. You both see a traffic light flash up ahead, and you both measure the exact same speed for light.

Worse yet, another friend with an identical device in an airplane traveling at 600 mph measures the speed of light from the same flash and gets the same answer for *c.*

A fourth friend traveling at half the speed of light in a rocketship repeats this same experiment and also gets the same value for *c*. How can this be?

It's possible only if our measurements of time and space are different. Einstein's second idea was to reject the notion that time and space are absolute.

Time and Space are *Not* Constant

The speed of light is the same in all reference frames. The only way for this to be possible is if the increments of time and space are different for different observers.

Common sense tells us that clocks tick at regular intervals, and that a meter stick does not change from one day to the next. Our common sense comes from our experience in the real world, which happens to be very limited in terms of speed. If we had learned as a baby to crawl at 90% the speed of light, then these ideas about space and time would make intuitive sense to us.

Since we don't travel anywhere near the speed of light, we often have trouble imagining what happens if we could. Our common sense isn't wrong, just limited. So it's time to expand it a little. Are you ready?

One of the first things you must do is watch your language. It's very easy to be biased and think that your viewpoint is the 'right one', but if you truly understand relativity, then you know this can't be true.

For example, in the traffic light example, if you were in the car and I was on the ground, I can't dismiss your observation because 'you were moving', because that would be saying that the laws of physics don't work if you're in motion. Both of us are able to do our physics experiments equally well. Even the friend in the rocketship – her data measurements are just as valid as mine.

So what happened? Are you thinking: *"Does something strange happen to moving clocks and meter sticks?"*

Watch your language! The minute you think that, you're implying that the clock and meter stick at rest are special and really the 'right' ones. The meter stick and clock in the plane are just as perfectly good as the ones in the rocketship and in the car and on the ground. The meter stick in the rocketship still reads one meter, and the clock still ticks by once every second.

The key is in the 'differences'. Let me explain:

First, let's describe an 'event'. An event is both a place and time. So, if you were born in '1980 in New York', then that is an *event*. To say you were born in 'New York' is not an event, and to say just '1980' is not an event. You need both, and you'll see why in just a moment.

Time Dilation

Time dilation is not about clocks or light, it's about time itself.

Measures of time are simply different for different observers in motion relative to each other.

Time dilation is often described by saying *"moving clocks run slow".* Can you see the problem with this statement? It infers that there's one clock that's right, and the rest are all slow, which totally violates the principle of relativity!

For relativity to hold true, the observer in the plane would feel nothing usual is happening whatsoever! The observer in the plane doesn't experience slow motion or anything else strange like that. In fact, the watch on her wrist still ticks by as it always has. She does not notice anything unusual in her reference frame.

What time dilation really says is this: suppose there are a set of identical twins on Earth. One twin gets into a rocketship and travels at 0.8c to a star 10 light years from Earth.

A light year is a measure of distance, not time. It's the distance light travels in a year. Light year is abbreviated by 'ly'. So the speed of light is one light year per year.

The twin still on Earth sees the other reach the star in 12.5 years:

Time = distance divided by speed:

Time = 10 ly divided by 0.8 ly per year to give 12.5 years.

But according to the twin in the rocketship, it takes only 7.5 years to reach the star 10 years light distant, using the equations for time dilation.

You really don't need to know this, but if you're curious, here's the equation for figuring this out:

$$t' = t\sqrt{1 - v^2}$$

t' is the time for the observer traveling at 0.8c.

v is the ratio of the traveling speed over *c*, so for 0.8c/c this becomes *v* = 0.8.

t = the time for the Earthbound twin.

$$t' = 12.5 years\sqrt{1 - (0.8)^2}$$

So t'=7.5 years!

Imagine the same star trip, but now the ship turns around and returns back to earth. According to the Earthbound twin, the whole trip takes 25 years. But according to the traveling twin, it took only 15 years. Now we have a set of identical twins who are ten years apart.

The traveling twin actually went ten years into the other's future. So time travel is possible.

In fact, the time traveling twin can do better by going faster! If she goes nearly *c* , the trip will take just over 25 years Earth time but the time for her will be only minutes and she can return 25 years younger than her twin.

She can also go farther than the 10-light year distant star. She can go to a star 1,000 light years away at near speed *c* and return 2,000 years later and only be moments older than when she left.

Does this really happen? Is this really possible?

Yes!

Here's the bad news: if she travels 2,000 years into the future and when she returns back to Earth finds that she doesn't like it, there's no going back. You can't travel in into the past. It's a one-way trip.

Can we do this with today's aircraft and rockets and spacecraft? Well, no, not yet. But here's what we have done: we've sent identical, synchronized clocks in fast airplanes around the Earth and measured the time against clocks that stay behind, and there is a measurable difference in the time read by both sets of clocks. Time really does travel at different rates in different frames of reference.

Can we really make objects travel at speeds near c? We can't accelerate large objects to high speeds anywhere near *c*, however we *can* get tiny subatomic particles to 99.995% the speed of light using a linear accelerator.

Faster than Light

So what happens when you're on a train traveling near the speed of light and you switch on the headlight?

Well, it depends on your reference point.

The person standing at the train station would see your headlight turn on, but it would be a different color depending on if you were heading toward them (blue headlight) or traveling away from them (red headlight).

If you're inside the train, you would see a white headlight.

In both cases the light travels at 186,000 miles per second.

Suppose you were inside the train, traveling near the speed of light and you have two light bulbs wired up to the same switch.

One bulb is at the front of the car, the second at the back of the car.

When you flip the switch, the light from both light bulbs hit your eyes at the same time, just as it you weren't moving. Is that what a stationary observer at the train station would see? Nope…

Someone sitting at the train station would see one light bulb turn on ahead of the other, and they would be different colors, even if they were wired to the same switch.

This is one of the strangest parts of relativity: events are not conserved. This means that two different people can see two different things happen, and also observe they occur at different time intervals.

Simultaneity is Relative

When we first look at time dilation there seems to be a big problem with it: "moving clocks run slow". But which clock is moving?

You might be tempted to say that the moving clock (the one with our time traveling twin) ran slow. Does this mean that the Earthbound twin's clock ran fast? Actually, the twin in the rocketship will say that the Earthbound twin's clock runs slow, too!

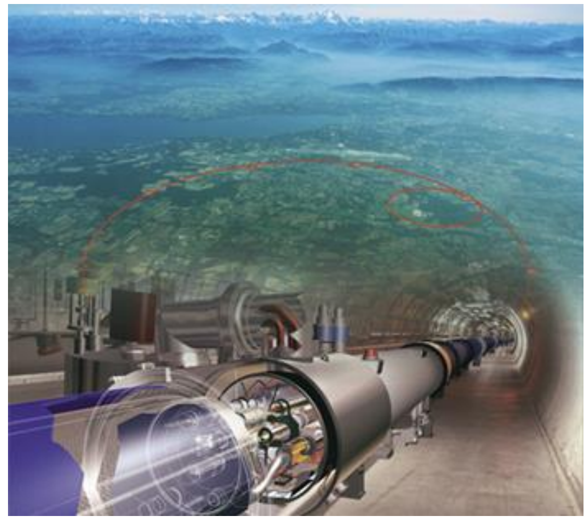
This seems like a paradox, but it really isn't. The traveling twin can claim she's at rest and the Earthbound twin is moving, so his clock is running slow. It all depends on your frame of reference.

Take another look at that star trip: the distance between Earth and the star must be less than 10 light-years as measured by the space ship's reference frame.

It turns out that length is also relative, in the direction of travel. An object is longest in a frame which it is at rest and shorter in frames that it is moving.

Once you do the math, it turns out that if you travel for 7.5 years at a speed of 0.8*c* you will cover a distance of 6 light years. So the distance to the star from the traveling twin's perspective is only 6 light years, not 10.

An example of this effect (called the Lorentz contraction) on Earth is at the Stanford Linear Accelerator, which is two miles long as measured on Earth. However, to an electron traveling at 0.9999995*c* , it's only three feet long. Engineers had to take relativity into account when designing this device or it wouldn't have been long enough to work!



You might be tempted again to say, but isn't it *really* 2 miles long? No!! You can't claim your reference frame is any more 'right' than the electron's. Be very careful with you talk about relativity, and leave the word 'really' out of it!

To further illustrate this point; let's take a look at an example involving two high-speed planes. We're going to compare how their ends line up differently depending on how you look at the situation:

Think about two high-speed planes moving in opposite directions where you're standing on the ground watching them pass overhead:

In this reference frame (above), both planes are viewed as moving, and their ends coincide at the same time. The tails of both planes meet at the same time and are simultaneous.

However, if you imagine you're in the upper plane watching the lower one, you'll see the lower plane contract in size along its length and also the right ends of the two planes coincide before the left ends do. So now these events (of the tails lining up at exactly the same time) are *not* simultaneous.

And in the frame of reference where you're watching the upper plane from the lower plane, the upper appears foreshortened and the left ends coincide first. The time order has reversed!

Whoa! Hold it! Does this mean that events can switch order?

Yes! Look at the second and third case of the high-speed planes – the events actually switch order!

What about cause and effect, then? After all, if events can switch their order around, can an effect come before the cause? Can a ball roll and then I kick it? Can a flower die before it blooms?

Actually, no. I turns out that the only events that the time order can be different for different observers are those special cases where the events are far enough apart in space that it would be impossible to get a light signal from one event to the other.

Remember that the time it takes between two events depends on your viewpoint. It may take 12.5 years to travel to a nearby star from a stationary observer, but only 7.5 light years for the one on the rocketship going at $0.8c$.

For example, when the Mars Rover landed on Mars, it was 11 light minutes from Earth (meaning that it would take a radio signal 11 minutes to get from Earth to Mars).

If NASA sent a signal to the Rover saying "go left at 5 mph", the Rover would get that signal in 11 minutes from when we sent it.

If a rock crushed the Mars Rover, we wouldn't know about it for 11 minutes here on Earth.

If we knew that 5 minutes from now, a rock was going to crush our Rover, is there anything we would do about it? No. it takes our signal too long to get there. No action on Earth can affect anything on Mars for 11 minutes.

A rock could have already crushed the Rover 5 minutes ago – can we know about it? No. Can Congress suddenly cut NASA's budget because the Rover was smashed? No. We have no way of knowing about anything happening on the surface from 11 minutes ago until now.

So we have a band of 22 minutes where nothing we do on Earth can possibly affect the Rover on Mars, and nothing that happens on mars can affect the Earth simply because there's no way for the information to get to us (or the Rover) in time.

Past events are those that can influence the present. Your birth is now the reason you are reading this sentence.

The future consists of all the events that the present can influence. The flower will bloom tomorrow because you planted a seed today.

So where does this window of 22 minutes fit in where the present actions do not influence the future?

It turns out that the events that are neither in the past nor the future are in the *elsewhere*. No kidding. It's just a name given to events that cannot be influenced by present actions.

Why is it impossible to go faster than light?

What happens if you launch a rocketship at 0.8*c* that was piggy-backed on another rocketship going at 0.8*c*? Can you go 1.6*c*?

Attempting to travel faster than light by 'leap-frogging' from one rapidly moving reference frame to another doesn't work because measures of time and space differ in different reference frames.

Another way to say it is that no *information* can travel faster than the speed of light.

There isn't anything special about light… it's really about time.

Sonic Boom for Light

One important note: it's impossible to go faster than the speed of light in a *vacuum*. Just like sound, light can change speeds depending on what it's going through. When you pass light through glass, it changes speed and angle (which allows you to focus the light in a pair of eyeglasses). You can actually slow light down to a crawl by passing it from the fifth state of matter (BEC).

In fact, you can have particles in a substance moving faster than light. An example is in water: scientists made high-energy subatomic particles move through water faster than light was traveling. When they did this experiment, something similar to a sonic boom occurred, only instead of a shock wave, a light cone was emitted called Cherenkov Radiation.

The Famous Equation: $E=mc^2$

When folks see the equation $E=mc^2$, they immediately think of relativity. In truth, this equation was not in the original paper about special relativity and was added two years later as an afterthought.

This famous equation tells us how mass and energy are related. It basically says that an pbject with mass *m* has an equivalent energy *E.* Notice how *m* is multiplied by the square of a huge number! Even a very small mass is going to have a large amount of energy.

Common Myth about $E=mc^2$

Most people don't understand that the *E* energy term means *all* the energy transformations, not just the nuclear energy.

The energy could be burning gasoline, fusion reactions (like in the sun), metabolizing your lunch, elastic energy in a stretched rubber band… every kind of energy stored in the mass is what *E* stands for.

For example, if I were to stretch a rubber band and somehow weigh it in the stretched position, I would find it weighed slightly more than in the unstretched position.

Why? How can this be? I didn't add any more particles to the system – I simply stretched the rubber band.

I added energy to the system, which was stored in the electromagnetic forces inside the rubber band, which add to the mass of the object (albeit very slightly).

Another Reason We Can't Go Faster Than Light

$E=mc^2$ gives us another way to realize how nothing can go faster than the speed of light.

A bowling ball is harder to get rolling than a ping pong ball because it has more inertia, more resistance to motion (we covered this in Unit 1).

The more massive an object, the more inertia it will have, and the more energy it will take to accelerate it.

The inertia increases as the object's speed approaches *c*, so it takes an infinite amount of force and thus infinite amount of energy to accelerate an object to *c.* And that is impossible.

Common Myths about Special Relativity

"Everything's relative…" Have you hear this before? Since Einstein published his work over a century ago, people from all over the board have applied it to their area of interest, including philosophy, aesthetics, morality, and other humanistic areas. But is that what Einstein really meant? Is everything really relative?

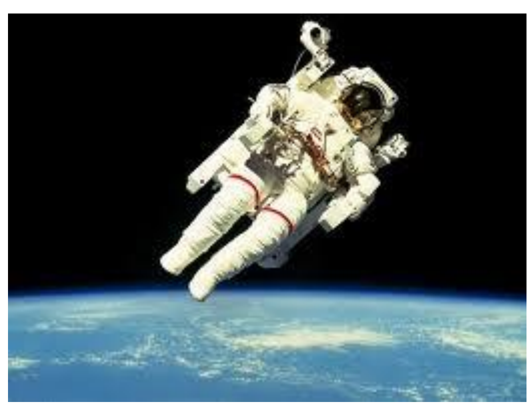
The happy answer is no. And you already know this – the laws of physics are not relative. They are the same for everyone. The speed of light isn't relative – it's the same for everyone, period.

And although observers differ on the intervals of time and space between two events, they do agree on certain aspects (we'll get to this when we talk about spacetime).

General Relativity Myths & Mistakes

One of the biggest mistakes made in science textbooks (especially in children's books) is the idea that there is no gravity in space.

You'll often see a picture of an astronaut "floating" right next to the words: *"Why does this astronaut float in space? Because there's no gravity in space."*



That's ridiculous! If there was no gravity in space, wouldn't the moon go veering off in a straight line? Wouldn't the planets stop orbiting the sun?

Sometimes you'll also see words to the effect of: *"You need to be free of the Earth's gravitational pull to experience weightlessness."*

Another ridiculous statement. You can experience freefall right here on Earth. Just go into an elevator to the top floor and cut the cord. You'll be in freefall in a very short amount of time.

If while in this freefalling elevator you took a ball out of your pocket and let it go, you'd see that it falls with the same acceleration that you do and will appear 'weightless'.

General Relativity

General Relativity states that you would not be able to tell if you were freefalling in an elevator with the cord cut or in an elevator box out in deep space (clear of any gravitational influences). They would be indistinguishable.

You'd know eventually you were freefalling on Earth because you'd smack into the ground and large forces would let you know you were not in deep space.

The astronaut in the space shuttle is in exactly the same situation of freefall as you were and therefore didn't feel gravity.

General Relativity came years after Special Relativity, as Einstein had to rearrange physics a bit in order to made sense of everything.

This is one of the very few theories which was not developed by the works of preceding scientists. Einstein came up with this all on his own in the laboratory of his mind by simply asking questions.

Although a hundred years old, General Relativity is not nearly as well-tested as Special Relativity.

Scientists know that Special Relativity is a proven fact, but they are only *mostly* sure about General Relativity.

It's incredible to think that one man's ideas nearly a century ago are still unable to be fully tested today due to lack of technology. Einstein was able to expect the universe to work a certain way without any experimental confirmation.

So... what *is* this theory exactly?

General Relativity states that the laws of physics are the same in *all* reference frames. Sound familiar? We had a similar notion in Special relativity, only now it's okay if objects are accelerating (speeding up or slowing down).

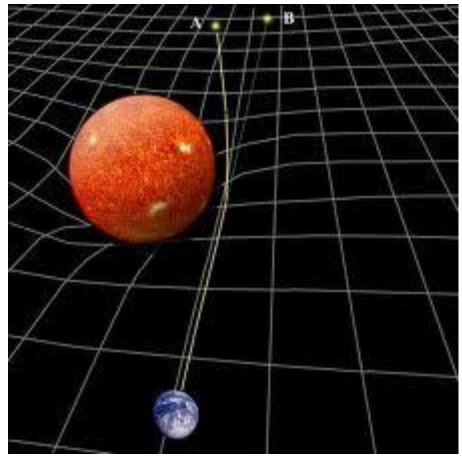
More precisely, absent any force, an object moves in the straightest possible path in curved spacetime.

What curves spacetime?

Simple – matter and energy. Both matter and energy can curve spacetime in their vicinity.

If you stretch a piece of plastic wrap (typically called *saran wrap* or *cling wrap*) in a large embroidery hoop and roll a ball across it, you'll see how the plastic deforms and curves around the ball.

Roll a smaller second ball (like a marble) near the first, and you'll find that the marble wants to curve toward the larger one where the plastic has been deformed. If you're careful, you can actually get the marble to orbit the larger ball for a bit. The marble's path is no longer in a straight line because of the presence of the larger ball.



For a long time, scientists had known that the path of Mercury didn't exactly follow the predicted by mathematics. This wasn't necessarily a problem for science – in fact, for many years astronomers believed a planet existed between the sun and Mercury that was tugging on Mercury and causing these small deviations in its expected orbit. (Scientists even named the missing planet Vulcan… but alas, they never found it.)

One of the first things Einstein did after developing his General Relativity ideas was to apply it to the orbit of Mercury. He was happy to find that it was a problem disappeared when General Relativity was used to solve the problem!

Since that time, astronomers have used General Relativity to explore the orbits of collapsed dense stars (neutron stars) that are in close orbits around each other.

Gravitational Time Dilation

General Relativity also predicts that time should run slower in places where gravity (spacetime curvature) is stronger. This means that clocks at the beach will run slower than clocks on a mountaintop.

In the 1960s, a very sensitive experiment was done at Harvard that had two identical clocks: one at the base and one at the tip of a 74-foot tower. The experiments verified that time did pass a different rate for both clocks!

It's important to take this effect into account with the GPS systems. Without it, our modern GPS system would be off by meters.

Nowadays, the atomic clocks in the GPS satellites run about 7.2 microseconds slower a day than earth-bound clocks, so scientists adjust their data to maintain accuracy.

Bending Light

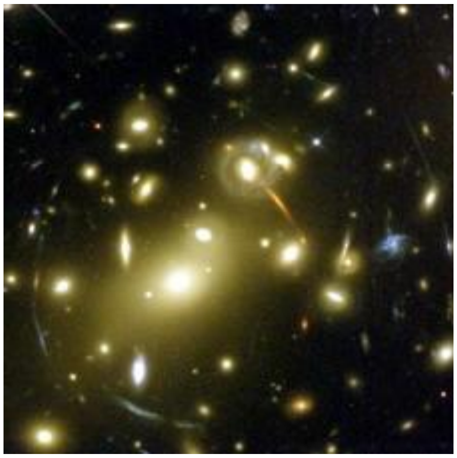
Light always travels in the straights possible path. But what happens if spacetime is curved? General relativity states that the path the light takes should also curve.

Einstein predicted that light from bright starts next to the sun would be bent as it passed the sun. The trouble is – you can't see starlight when the sun is up.

A famous experiment took place during the total solar eclipse of 1919. Sir Aurthur Eddington led an expedition to take measurements during the solar eclipse to verify that light does curve around objects.

Eddington waited until the moon blocked out the sun before he took photographs on glass plates and compared them with the positions they would have had at another time of year (when they are not next to the sun). He found that the stars position was shifted slightly, verifying Einstein's prediction that light can be bent by gravity.

Today astronomers use this effect (called gravitational lensing) to detect large, dark objects like black holes and pulsars. The light from the distant objects they observe gets bent and distorted to form streaks and double-images on the camera.



Gravitational Waves

An exciting area of science are trying to figure out how to detect gravitational waves.

General relativity predicts that ripples in the fabric of spacetime should travel at the speed of light. Scientists named this effect gravitational waves. As of yet, we have not been able to detect any.

Scientists have been able to detect that a gravitational wave was present, but they have not been able to find the wave itself.

Black Holes

True or false? *"What goes up must come down."*

If you toss a ball up in the air, it does indeed come back down. If you toss it up higher, it does return back to you. What if you toss it so high that it breaks free of the Earth's gravitational pull and escapes?

We call this special threshold speed the "escape speed". For the Earth, it's about 7 miles per second. For the sun, it's around 400 miles per second.

This means you need to throw a ball with a speed of 7 miles per second in order for it never to come back down. If you throw it harder than this, it will not only escape but have enough speed to spare.

We did this with the Voyager missions (which have just passed the heliosphere and are no longer under the influence of the sun).

What if we squeezed the Earth down to half its size? We still stand on the surface, but the Earth is much more tightly packed together, and now you try to toss the ball up in the air. What happens to its required escape speed? Did it increase or decrease?

Since the mass of the Earth did not change, the escape speed actually increased. Now we need a much faster speed to escape the pull of

Earth's gravity because we're closer to the center of the Earth.

If we continue to squeeze the Earth down to the size of a ping pong ball, the gravitational pull is becoming so great that now the required escape speed is approaching the speed of light.

A black hole is an object whose escape speed exceeds the speed of light. General relativity predicts black holes also!

For our sun to become a black hole, we'd have to squeeze it into a ball about 4 miles in diameter, so you're safe – the sun will never turn into a black hole. It's not small enough and does not have nearly enough mass (it needs at least three times its current mass to do so).

Black holes are formed from intense supernova explosions or by large objects colliding together.

Black holes are also called 'frozen stars' because time stops at the event horizon (the point of no return). This is the place where if you cross over this line into the black hole, there's no coming back out.

Time slows in regions of higher gravitational forces. Black holes have such huge gravitational forces that time slows to a standstill.

Myths about Black Holes

Black holes are not vacuum cleaners with infinite sized bags. They do not roam around the universe sucking up everything they can find.

They will grow gradually as stars and matter falls into them, but they do not seek out prey like predators.

Activities, Experiments, Projects

Lesson 1: Particle Physics

Note: This section is an abbreviated overview of the experiments online.

Experiment: Alpha Particle Detector

Here is another way to detect cosmic rays, only this time you'll actually see the thin, threadlike vapor trails appear and disappear. These cobwebby trails are left by the particles within minutes of creating the detector.

In space, there are powerful explosions (supernovas) and rapidly-spinning neutron stars (pulsars), both of which spew out high energy particles that zoom near the speed of light. Tons of these particles zip through our atmosphere each day. There are three types of particles: alpha, beta, and gamma.

Did you know that your household smoke alarm emits alpha particles? There's a small bit (around 1/5000th of a gram) of Americium-241, which emits an alpha particle onto a detector. As long as the detector sees the alpha particle, the smoke alarm stays quiet. However, since alpha particles are easy to block, when smoke gets in the way and blocks the alpha particles from reaching the detector, you hear the smoke alarm scream.

Alpha particles are actually high speed helium nuclei (which is two protons and two neutrons stuck together). They were named long before we knew what they were of, and the name stuck. Alpha particles are pretty heavy and slow, and most get stopped by just about anything, a sheet of paper or your skin. Because of this, alpha particles are not something people get excited about, unless you actually eat the smoke detector.

Both brick buildings as well as people emit beta particles. Beta particles are actually high speed electrons or positrons (a positron is the antimatter counterpart to the electron), and they are quick, fast, and light. You can stop a beta particle by holding up a thin sheet of plastic or tinfoil.

When you hold the jar in your hands, you warm it slightly and cause the air inside to get saturated with alcohol vapor. When the alpha particles (cosmic rays) zip through this portion of the jar, they quickly condense the alcohol and create spider-webby vapor trails. Try using a magnet to deflect the cosmic rays.

Experiment: Cosmic Ray Detector

When high energy radiation strikes the Earth from space, it's called *cosmic rays*. To be accurate, a cosmic ray is not like a ray of sunshine, but rather is a super-fast particle slinging through space. Think of throwing a grain of sand at a 100 mph… and that's what we call a 'cosmic ray'.

Most cosmic rays zoom to us from extra-solar sources (*outside* our solar system but *inside* our galaxy) such as high-energy pulsars, grazing black holes, and exploding stars (supernovae). We're still figuring out whether some cosmic rays started from outside our own galaxy. If they are from outside our galaxy, it means that we're getting stuff from quasars and radio galaxies, too!

Cosmic rays have a positive charge, as the particles are usually protons, though one in every 100 is an electron (which has a negative charge) or a muon (also a negative charge, but 200 times heavier than an electron). On a good day, your cosmic ray indicator will blip every 4-5 seconds. These galactic cosmic rays are one of the most important problems for interplanetary travel by crewed spacecraft.

Quantum Mechanics: Double Slit Experiment

This stuff is definitely sci-fi weird, and probably not appropriate for younger grades (although we did have a seven year old reiterate in his own words this exact phenomenon to a physics professor, so hey… anything possible! Which is why we've included it here.)

This experiment is also known as Young's Experiment, and it demonstrates how the photon (little packet of light) is both a particle and a wave, and you really can't separate the two properties from each other. If the idea of a 'photon' is new to you, don't worry – we'll be covering light in an upcoming unit soon. Just think of it as tiny little packets or particles of light. I know the movie is a little goofy, but the physics is dead-on. Everything that "Captain Quantum" describes is really what occurred during the experiment.

Activities, Experiments, Projects

Lesson 2: Astronomy

Note: This section is an abbreviated overview of the experiments online.

Experiment: Star Trails

These are a set of videos made using planetarium software to help you see how the stars and planets move over the course of months and years.

Experiment: Space Shuttle Launch

Something every person should do in their lifetime is watch a rocket or space shuttle launch. Since this is getting harder and harder, and most folks don't live in a convenient area for viewing launches, here's one of the best launches filmed on video. STS-119 (ISS assembly flight 15A) was a space shuttle mission to the International Space Station (ISS) which was flown by Space Shuttle Discovery during March 2009.

Experiment: Apollo 11 and Saturn V Rocket Launch

This is the actual video of the very first moon landing of the Apollo 11 mission in 1969! Neil Armstrong was the first man to set foot on the moon with his now legendary words *"One small step for man, a giant leap for mankind."* This is a truly amazing video. If you think about it, you have orders of magnitude more processing power in your mobile phone than they did in the whole space craft!! Incredible!

Experiment: Meteorites

A meteoroid is a small rock that zooms around outer space. When the meteoroid zips into the Earth’s atmosphere, it’s now called a meteor or “shooting star”. If the rock doesn’t vaporize en route, it’s called a meteorite as soon as it whacks into the ground. (The word meteor comes from the Greek word for “high in the air”.)

For meteorite-hunters, look for rocks that are black, heavy (almost twice the normal rock density), and magnetic. Note – there is an Earth-made rock that is also black, heavy, and magnetic (magnetite) that is not a meteorite. To tell the difference, scratch a line from both rocks onto an unglazed tile (or the bottom of a coffee mug or the underside of the toilet tank). Magnetite will leave a mark whereas the real meteorite will not.

If you find a meteorite, head to your nearest geology department at a local university or college and let them know what you've found. In the USA, if you find a meteorite, you get to keep it… but you might want to let the experts in the geology department have a thin slice of it to see what they can figure out about your particular specimen.

Here's an option for meteorite hunters: place a sheet of white paper outside on the ground. After a few hours, your paper starts to show signs of "dust". Carefully place a magnet underneath the paper, and see if any of the particles move as you wiggle the magnet. If so, you've got yourself a few bits of space dust!

Experiment: Retrograde Motion

If you watch the moon, you'd notice that it rises in the east and sets in the west. This direction is called 'prograde motion'. The stars, sun, and moon all follow the same prograde motion, meaning that they all move across the sky in the same direction.

However, at certain times of the orbit, certain planets move in 'retrograde motion', the opposite way. Mars, Venus, and Mercury all have retrograde motion that have been recorded for as long as we've had something to write with. While most of the time, they spend their time in the 'prograde' direction, you'll find that sometimes they stop, go backwards, stop, then go forward again, all over the course of several days to weeks.

Experiment: Satellite Crash

The Hubble Space Telescope (HST) zooms around the Earth once every 90 minutes (about 5 miles per second), and in August 2008, Hubble completed 100,000 orbits! Although the HST was not the first space telescope, is the one of the largest and most publicized scientific instrument around. Hubble is a collaboration project between NASA and the ESA (European Space Agency), and is one of NASA's "Great Observatories" (others include

Compton Gamma Ray Observatory, Chandra X-Ray Observatory, and Spitzer Space Telescope). Anyone can apply for time on the telescope (you do not need to be affiliated with any academic institution or company), but it's a tight squeeze to get on the schedule.

The HST orbit zooms high in the upper atmosphere to steer clear of the obscuring haze of molecules in the sea of air. Hubble's orbit is slowly decaying over time and sometime after 2010, if left unchecked, will begin to spiral back into Earth.

Experiment: Star Charting

If you want to get from New York to Los Angeles by car, you'd pull out a map. If you want to find the nearest gas station, you'd pull out a smaller map. What if you wanted to find our nearest neighbor outside our solar system?

A star chart is a map of the night sky, divided into smaller parts (grids) so you don't get too overwhelmed. Astronomers use these star charts to locate stars, planets, moons, comets, asteroids, clusters, groups, binary stars, black holes, pulsars, galaxies, planetary nebulae, supernovae, quasars, and more wild things in the intergalactic zoo.

Most star charts available to the public, however, show the position of stars, connecting them like a game of dot-to-dot, creating odd pictures that don't even remotely look like their description. "Sagittarius", for example, looks more like a teapot than a great archer. Let's see if we can make sense of these sky maps.

The first thing to star chart is the Big Dipper, or other easy-to-find constellation (alternates: Cassiopeia for northern hemisphere or the Southern Cross for the southern hemisphere). The Big Dipper is always visible in the northern hemisphere all year long, so this makes for a good target.

Use glow in the dark stars instead of rocks, and charge them with a quick flash from a camera (or a flashlight). Keep your hand as still as you can while the second person lines the rock into position. You can also unroll a large sheet of (butcher or craft) paper and use markers to create a more permanent star chart.

Experiment: Build a REAL Scale Model of the Solar System

Ever wonder exactly how far away the planets really are? Here's the reason they usually don't how the planets and their orbits to scale - they would need a sheet of paper nearly a mile long!

To really get the hang of how big and far away celestial objects really are, find a long stretch of road that you can mark off with chalk. We've provided approximate (average) orbital distances and sizes for building your own scale model of the solar system.

When building this model, start by marking off the location of the sun (you can use chalk or place the objects we have suggested below as placeholders for the locations). Are you ready to find out what's out there? Then let's get started. You need a measuring tape (the biggest one you have) as well as tape or chalk to mark off the locations as you go along. All distances are measured from the center of the sun. (In some cases, you might just want to use the odometer in your car to help you measure the distance!)

Sun (12" beach ball) at the starting point.

Mercury (grain of sand) is 41 feet from the sun.

Venus (single peppercorn) is 77 feet from the sun.

Earth (single peppercorn) is 107 feet from the sun.

Mars (half a peppercorn) is 163 feet from the sun.

Jupiter (golf ball) is 559 feet from the sun.

Saturn (shooter-size marble) is 1,025 feet from the sun.

Uranus (regular-size marble) is 2,062 feet from the sun.

Neptune (regular marble) is 3,232 feet from the sun.

Pluto (grain of sand) is 4,248 feet from the sun.

Nearest Star (Alpha Centauri) is 5500 miles from the sun.

Experiment: Is Your Solar System Too Big?

If these distances are too large for you, simply shrink all objects to the size of the period at the end of this sentence and you'll get your solar system to fit inside your house using these measurements below.

First, draw a tiny dot for the Sun. The diameter of the sun for this scale model is 0.1", but we're going to ignore this and all other planet diameters so we can fit this model within a 35' scale.

We're going to ignore the sizes of the planets and just focus on how far apart everything is. All distances listed below are measured from the sun. Start by marking off the position of the sun with the tip of a sharp pencil.

Here are the rest of the distances you need to mark off:

Mercury is 4 inches from the sun.

Venus is 7.75 inches from the sun.

Earth is 10 inches from the sun.

Mars is 1' 4" from the sun.

Jupiter is 4' 8" from the sun.

Saturn is 8' 6.5" from the sun.

Uranus is 17' 2" from the sun.

Neptune is 26' 11" from the sun.

Pluto is 35' 5" from the sun.

Our nearest star, **Alpha Centauri**, is approximately 46 miles from the sun.

Are you mind-boggled yet? Did you notice how the solar system is really just 'empty space'? Our models shown here are too small to start bringing in the moons, but you can see why posters showing the planets are not drawn to scale.

Experiment: Solar System Treasure Hunt

After you've participated in the Planetarium Star Show (either a live presentation or by listening to the MP3 download for Unit 7), treat your kids to a Solar System Treasure Hunt! You'll need some sort of treasure (we recommend books like Nightwatch or a pair of Aurora's favorite binoculars, but you can also use 'Mars' candy bars or home made chocolate chip cookies (call them *Galaxy Clusters*) instead.

Astronomy Clues
You can print out images of each planet and match them up with the clues indicated below. Post images of each of the planets along with the clue for the next one to really make this an out-of-this-world experience!

The Sun *(CLUE #1): Hand this one to the kids to get started.*
This object is hot, but not on fire.
Explore the dryer but don't perspire!

Mercury *(CLUE #2): Hide this clue below in the dryer.*
This planet is closest, but not the hottest.
Check the sock drawer, and don't be modest!

Venus *(CLUE #3): Hide this clue below in the sock drawer.*
This planet is so hot it can melt a cannonball,
Crush spaceships, rain acid, and is in tree tall.

Earth *(CLUE #4): Hide this clue below in a tree (or plant).*
Most of this planet is covered with water.
Visit the bathtub without making it hotter.

Mars *(CLUE #5): Hide this clue below in the bathtub.*
This planet is basically a rusty burp.
Discover the refrigerator and take a slurp.

Jupiter *(CLUE #6): Hide this clue below next to the milk.*
A planet so large it can hold the rest,
Explore our library with infinite zest!

Saturn *(CLUE #7): Hide this clue below with a stack of books.*
This planet had rings, but not made of gold.
Explore near the front door like an astronaut bold!

Uranus *(CLUE #8): Hide this clue below on the front door.*
Smacked so hard it now rolls on its side,
Find the window that is ever so wide.

Neptune *(CLUE #9): Hide this clue below by sticking it on a window.*
Check the sink for hurricane, gigantic blue farts, and diamond rain.

Pluto *(CLUE #10): Hide this clue below near the sink with the TREASURE!*
Instead of one there were two, then four…
Visit the mailbox for the one that is no more.

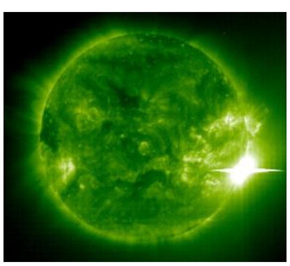
Experiment: Recent Astronomical Events

Comet Shoemaker Levy Colliding with Jupiter

Spectacular images of Jupiter during and after impacts, when over twenty fragments of Comet Shoemaker-Levy 9 smashed into the planet in July 1994.

Solar Flares caught by SOHO

This mega-flare was seen being spewed out by the Sun, captured by SOHO's Extreme ultraviolet Imaging Telescope. *Why does the Sun flare?* Unpredictably, our Sun unleashes tremendous flares expelling hot gas into the Solar System that can affect satellites, astronauts, and power grids on Earth.



This close up of an active region on the Sun that produced a powerful X-class flare was captured by the orbiting TRACE satellite. The glowing gas flowing around the relatively stable magnetic field loops above the Sun's photosphere has a temperature of over ten million degrees Celsius.

These flows occurred after violently unstable magnetic reconnection events above the Sun produced the flare. Many things about solar active regions are not well understood including the presence of dark regions that appear to move inward.

NASA's Deep Impact Mission

Launch and flight teams are in final preparations for the planned Jan. 12, 2005, liftoff from Cape Canaveral Air Force Station, Fla., of NASA's Deep Impact spacecraft. The mission is designed for a six-month, one-way, 431 million kilometer (268 million mile) voyage. Deep Impact will deploy a probe that essentially will be "run over" by the nucleus of comet Tempel 1 at approximately 37,000 kilometers per hour (23,000 miles per hour). It's like hitting a comet with something the size of a fridge.

Galileo Probe Mission to Jupiter

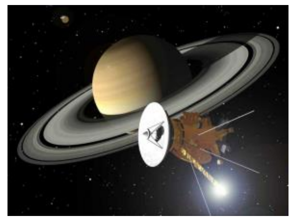
Galileo was an unmanned spacecraft sent by NASA to study the planet Jupiter and its moons. Named after the astronomer and Renaissance pioneer Galileo Galilei, it was launched on October 18, 1989 by the Space Shuttle Atlantis on the STS-34 mission. It arrived at Jupiter on December 7, 1995, a little more than six years later, via gravitational assist flybys of Venus and Earth.

Galileo conducted the first asteroid flyby, discovered the first asteroid moon, was the first spacecraft to orbit Jupiter, and launched the first probe into Jupiter's atmosphere.

On September 21, 2003, after 14 years in space and 8 years of service in the Jovian system, Galileo's mission was terminated by sending the orbiter into Jupiter's atmosphere at a speed of nearly 50 kilometres per second to avoid any chance of it contaminating local moons with bacteria from Earth. Of particular concern was the ice-crusted moon Europa, which, thanks to Galileo, scientists now suspect harbors a salt water ocean beneath its surface.

Cassini-Huygens Mission to Saturn

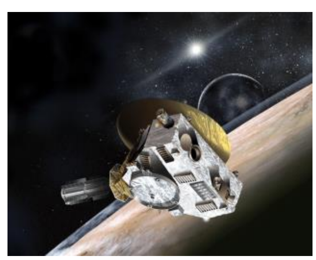
The incredible journey to Saturn and Titan. Cassini completed its initial four-year mission to explore the Saturn System in June 2008. Now, the healthy spacecraft is working overtime on the Cassini Equinox Mission, seeking answer to new questions raised in Cassini's first years at Saturn.



The mission's extension, through September 2010, is named for the Saturnian equinox, which occurs in August 2009 when the sun will shine directly on the equator and then begin to illuminate the northern hemisphere and the rings' northern face. Cassini will observe seasonal changes brought by the changing sun angle on Saturn, the rings, and moons, which were illuminated from the south during the mission's first four years.

Source: NASA Website

New Horizons Mission to Pluto



New Horizons passed Jupiter early 2007 and snapped photos we now have of the gas giant. New Horizons' voyage through the Jupiter system in 2007 provided a bird's-eye view of a dynamic planet that has changed since the last close-up looks by NASA spacecraft.

Historic Missions

Voyager Mission

In 1977, NASA launched two small spacecraft called Voyager 1 and Voyager 2. Weighing only 800 kgs each, they collected a wealth of scientific data and thousands of photographs of the four giant planets in our Solar System. After visiting Jupiter and Saturn, Voyager 1's trajectory left the ecliptic plane in order to photograph Saturn's moon Titan. This meant that Voyager 1 would not visit any other planets. However, Voyager 2 continued on to visit Uranus and Neptune. Still today, Voyager 2 is the only spacecraft to have visited these two "ice giants" and their moons.

Pioneer 10

Launched on March 2, 1972, Pioneer 10 was the first spacecraft to travel through the asteroid belt, and the first spacecraft to make direct observations and obtain close-up images of Jupiter. Pioneer 10 is now coasting silently through deep space toward the red star Aldebarran, a journey of over 2 million years.

Mariner 10 Mission

Mariner 10 was a robotic space probe launched on 3 November 1973 to fly by the planets Mercury and Venus. It was launched approximately 2 years after Mariner 9 and was the last spacecraft in the Mariner program (Mariner 11 and 12 were redesignated Voyager 1 and Voyager 2). The mission objectives were to measure Mercury's environment, atmosphere, surface, and body characteristics and to make similar investigations of Venus. Secondary objectives were to perform experiments in the interplanetary medium and to obtain experience with a dual-planet gravity-assist mission.

During its flyby of Venus, Mariner 10 discovered evidence of rotating clouds and a very weak magnetic field.

Mariner 10 flew past Mercury three times in total. Owing to the geometry of its orbit — its orbital period was almost exactly twice Mercury's — the same side of Mercury was sunlit each time, so it was only able to map 40-45% of

Mercury's surface, taking over 2800 photos. It revealed a more or less moon-like surface. It thus contributed enormously to our understanding of the planet, whose surface had not been successfully resolved through telescopic observation.

Apollo 11 Mission

The purpose of the Apollo 11 mission was to land men on the lunar surface and to return them safely to Earth. The crew was Neil A. Armstrong, commander; Michael Collins, Command Module pilot; and Edwin E. Aldrin Jr., Lunar Module pilot.

After launch, the spacecraft was inserted into lunar orbit about 76 hours into the mission. The spacecraft landed in the Sea of Tranquillity at 4:18 p.m. EDT. A Lunar Module camera provided live television coverage of Armstrong setting foot on the lunar surface at 10:56 p.m. EDT. Just as he stepped off the Lunar Module Neil Armstrong proclaimed, "That's one small step for a man, one giant leap for mankind." Forty-seven pounds of lunar surface material were collected to be returned for analysis. The surface exploration was concluded in 2½ hours, when the crew re-entered the lunar module to return safely home.

Source: NASA Website

Exercises for Unit 7: Astrophysics

Lesson 1: Particle Physics Exercises

1. All visible matter is made up of…?
2. What is a quark?
3. What's the charge on an electron, proton, and neutron?
4. What keeps the quarks together inside a proton?
5. Are free neutrons or protons more stable?
6. What forces are the 79 protons together inside a gold atom feeling?
7. Why does an electron stick around to orbit a nucleus?
8. Where can you find anti-matter on Earth?
9. What's the difference between fusion and fission?
10. Where can you find radiation?

Exercises for Unit 7: Astrophysics

Lesson 2: Astronomy Exercises

1. If a mad scientist pointed his alpha particle gun straight at you, what would be your best defense?

2. Did Pluto get smacked out of existence, or is it still there? What other 'planet' did this happen to?

3. How accurate is the main idea in the 2007 movie "Sunshine", where the mission was to reignite the sun?

4. How do you make a black hole?

5. How can you detect a black hole?

6. What happens if your car zooms at nearly the speed of light and turn on your headlights?

7. What's your favorite part about Jupiter?

8. Which planet is NOW your favorite (after listening to the astronomy teleclass)?

9. What happened to the stars in the slideshow/teleclass?

10. Which stars don't twinkle?

11. How many moons can you see with binoculars?

Exercises for Unit 7: Astrophysics

Lesson 3: Relativity

1. What's wrong with the statement "moving clocks run slow"? Can you find this or a similar "relativistically incorrect" statement in a book on relativity?
2. Suppose two triplets leave Earth at the same time and undertake roundtrip space journeys of identical length and at the same speed but in opposite directions. When they return, will they be the same age or will one be older? How will their ages compare with their third sibling, who stayed at home on Earth?
3. In 1999, scientists discovered a planetary system orbiting a star 44 light-years from Earth. How far into the future could you travel by taking a high-speed trip to this star and returning immediately back to Earth? Under what conditions would you achieve this maximum future travel? How long would you judge the trip to take?
4. Suppose the twin in the spaceship traveled at 0.6c instead of 0.8c. By how much would the twins' ages differ when the traveling twin returns to Earth?
5. A famous "paradox" of relativity is the following: A high-speed runner carries a 10-foot-long pole toward a barn that is 10 feet long and has doors open at both ends. The runner is going so fast that, from the point of view of the farmer who owns the barn, the pole is only 5 feet long. Clearly, the farmer can close both barn doors and trap the runner in the barn. But to the runner, the pole is 10 feet long and the barn, rushing toward the runner, is only 5 feet long. So clearly the runner can't be in the barn with both doors closed. Can you resolve the paradox, using the fact that events simultaneous in one reference frame aren't simultaneous in another? (By the way, the speed required here is 0.866c.)
6. Right now it's "the present," but is it "the present" everywhere? Explain your answer.
7. What's wrong with the definition "the past consists of those events that have already happened"?

8. You throw a bunch of subatomic particles into a closed box, the walls of which block the passage of matter but not energy. Must the number of particles in the box remain the same? Explain.
9. You drop a large rock and a small rock. Because of its larger mass, the gravitational force on the larger rock is greater. Why doesn't the larger rock fall with greater acceleration?
10. An airplane flying from San Francisco to Tokyo first heads north toward the coast of Alaska. Why? How is this analogous to what happens in general relativity's description of gravity?
11. In special relativity, we stressed that time dilation is reciprocal: When we're moving relative to each other, I see your clock running slow, and you see mine running slow. Now we have gravitational time dilation in general relativity: If you're closer to Earth or another gravitating body than I am, I see your clock running slow. Do you expect this effect to be reciprocal too, or will you see my clock running fast?
12. Gravity seems a pretty formidable force if you're trying to lift a heavy object or scale a cliff. In what sense, though, is gravity on Earth (and indeed throughout our solar system) weak?
13. If the Earth suddenly shrank to become a black hole, with no change in mass, what would happen to the moon in its circular orbit?
14. If you were falling into a black hole and looked at your watch, would you notice time "slowing down"? Justify your answer using basic principles of relativity.
15. You are on a jet flying 600 mph through calm air. You open a bag of peanuts while the slight attendant pours your tea into a cup on your tray. Why do you suppose that you don't have to take into account the jet's motion when the tea and peanuts travel at 600 mph?
16. Many people think astronauts in space are weightless because there's no gravity in space. How would Newton argue against this?
17. Maxwell's equations predict the existence of EM waves (light) going at speed c… but with respect to what? Relative to what?

Answers to Particle Physics Exercises

1. All visible matter is made up of electrons, protons and neutrons.
2. A quark makes up the nucleus of an atom. A proton is made up of two up quarks and one down quark. A neutron is made up of one up quark and two down quarks.
3. An electron has a negative charge, a proton has a positive charge, and a neutron has no charge.
4. The gluons hold the quarks together to form neutrons and protons.
5. Free neutrons flip into a more stable proton within 15 minutes.
6. The protons are feeling an electromagnetic 'repulsive push' force, as they are all the same charge. (Think of how two north sides of a magnet don't like each other.) However, the residual strong force is much stronger at the atomic scale and overcomes the repulsive force and pions bind the protons together.
7. An electron has a negative charge, which is attracted to the positive charge of the protons inside the nucleus.
8. A PET scan is a way of imaging using positrons. Patients ingest anti-matter and a machine takes pictures of the puffs of energy given off by the colliding matter (electrons) and anti-matter (positrons).
9. Fission is splitting atoms apart, and fusion is smooshing them together. An atomic bomb uses fission, and the sun uses fusion.
10. When an atom spontaneously undergoes fission (splitting), it's called fission. Uranium 235 is an example of an element that does this.

Answers to Astronomy Exercises

1. Hold up a sheet of paper between you and the gun.
2. Pluto was once considered one of the planets, but in recent years was demoted to 'dwarf planet' status and is now part of the Kuiper Belt Objects. Ceres underwent the same sort of thing in the 1800s, and now belongs to the asteroid belt between Mars and Jupiter.
3. The sun is not on fire, like a candle. You can't blow it out or reignite it. The nuclear reactions deep in the core transforms 600 million tons per second of hydrogen into helium using a chemical processes called the proton-proton chain.
4. When a star uses up its fuel, the way it dies depends on how massive it was to begin with. Large stars can go supernova and collapse in on themselves indefinitely, forever.
5. By looking at oddball things that happen around the black hole. For example, light getting distorted and forming streaks and multiple images where there should be only one object, or watching an object get yanked about without anything visible around to the pulling, x-rays and gamma ray jets, or the accretion disk ring lighting up.
6. You would see white headlights coming from the front of your car, but a friend sitting on the ground miles ahead of you, watching you race toward them would see you turn on blue headlights.
7. Take your pick: MASERs shooting out of the poles of Jupiter; the way Jupiter shocks Io with 3 million amps every time it crosses its magnetic fields; Io belching itself inside-out; needing windshield wipers if you stay in orbit around Io… the list goes on and on.
8. Most people settle their focus on Neptune and/or Venus after the teleclass.
9. Barnard 68 is an example of a dark nebula. It absorbs all light (energy) and is the coldest spot we've ever found out there in the universe. The stars are still there, but behind the dark cloud.
10. Planets don't twinkle, but stars do. It's an easy way to spot Jupiter, Saturn, Venus, and Mercury.
11. You can see our Moon, four moons of Jupiter (Ganymede, Io, Europe, and Callisto), and four of Saturn.

Answers to Relativity Exercises

1. What's wrong with the statement "moving clocks run slow"? Can you find this or a similar "relativistically incorrect" statement in a book on relativity? This implies that there is something special about one reference frame over another. Relativity states that all reference frames are equal.

2. Suppose two triplets leave Earth at the same time and undertake roundtrip space journeys of identical length and at the same speed but in opposite directions. When they return, will they be the same age or will one be older? How will their ages compare with their third sibling, who stayed at home on Earth? The two will return the same age but arrive younger than the Earthbound triplet.

3. In 1999, scientists discovered a planetary system orbiting a star 44 light-years from Earth. How far into the future could you travel by taking a high-speed trip to this star and returning immediately back to Earth? Under what conditions would you achieve this maximum future travel? How long would you judge the trip to take? The traveling person could take only minutes or second to make the trip, and an Earthbound observer would see the trip as taking just over 88 years. The traveler would arrive just over 88 years into the future at the same age as they left.

4. Suppose the twin in the spaceship traveled at 0.6c instead of 0.8c. By how much would the twins' ages differ when the traveling twin returns to Earth? The traveling twin would have taken 20 years instead of 15 years for the trip, so their age difference would be only five years upon return.

5. A famous "paradox" of relativity is the following: A high-speed runner carries a 10-foot-long pole toward a barn that is 10 feet long and has doors open at both ends. The runner is going so fast that, from the point of view of the farmer who owns the barn, the pole is only 5 feet long. Clearly, the farmer can close both barn doors and trap the runner in the barn. But to the runner, the pole is 10 feet long and the barn, rushing toward the runner, is only 5 feet long. So clearly the runner can't be in the barn with both doors closed. Can you resolve the paradox, using the fact that events simultaneous in one reference frame aren't simultaneous

in another? (By the way, the speed required here is 0.866c.) From the runner's point of view, the pole will reach the second door before the pole clears the first door. From the farmer's point of view, the pole will reach the second door after it clears the first door. The events are not in the same order for both viewpoints. Yet both are right. These events are not simultaneous.

6. Right now it's "the present," but is it "the present" everywhere? Explain your answer. No. It is elsewhere in events that are too far away to influence any events occurring right now.

7. What's wrong with the definition "the past consists of those events that have already happened"? Who's past? Since events can be different depending on your viewpoint, my past may not be the same as yours. You might see two lights switch on at the same time whereas I saw one light up before the other; hence our past experiences are different. Yet both are correct.

8. You throw a bunch of subatomic particles into a closed box, the walls of which block the passage of matter but not energy. Must the number of particles in the box remain the same? Explain. No. If two particles combine and annihilate each other (a positron and electron, for example), then the number of particles will decrease but the amount of energy generated may escape.

9. You drop a large rock and a small rock. Because of its larger mass, the gravitational force on the larger rock is greater. Why doesn't the larger rock fall with greater acceleration? The larger rock has more inertia (resistance to motion) and takes longer to accelerate. And it probably is larger and will have more air drag as well, although this problem didn't mention this effect.

10. An airplane flying from San Francisco to Tokyo first heads north toward the coast of Alaska. Why? How is this analogous to what happens in general relativity's description of gravity? The shortest distance on a sphere is the Great Circle Distance. Gravity curves spacetime and objects will now travel along a curve that takes the shortest possible line along this curved path.

11. In special relativity, we stressed that time dilation is reciprocal: When we're moving relative to each other, I see your clock running slow, and you see mine running slow. Now we have gravitational time dilation in general relativity: If you're closer to Earth or another gravitating body than I am, I see your clock running slow. Do you expect this effect to be reciprocal too, or will you see my clock running fast? I will see your clock running at a different rate than mine due to gravitational time dilation.

12. Gravity seems a pretty formidable force if you're trying to lift a heavy object or scale a cliff. In what sense, though, is gravity on Earth (and indeed throughout our solar system) weak? The escape speed is very slow compared to the speed of light.

13. If the Earth suddenly shrank to become a black hole, with no change in mass, what would happen to the moon in its circular orbit? Nothing. The moon does not care what shape the Earth is. It's only responding to the mass of the Earth.

14. If you were falling into a black hole and looked at your watch, would you notice time "slowing down"? Justify your answer using basic principles of relativity. No, you would see the clock ticking by as usual as you passed the event horizon and drifted in for awhile, until you were stretched thin from the gravitational forces of the black hole and shredded at the subatomic level.

15. You are on a jet flying 600 mph through calm air. You open a bag of peanuts while the slight attendant pours your tea into a cup on your tray. Why do you suppose that you don't have to take into account the jet's motion when the tea and peanuts travel at 600 mph? My reference frame is in uniform motion (constant speed and in a straight line) and thus just as good as the stationary observer at the airport. I observe nothing unusual going on in my reference frame. The laws of physics apply to my viewpoint just as well as any other reference frame in uniform motion.

16. Many people think astronauts in space are weightless because there's no gravity in space. How would Newton argue against this? There IS gravity in space, otherwise the planets would not orbit around the sun. The weightless the astronaut feels has to do with the orbit he takes around the Earth – the astronaut is not just 'sitting' out there in orbit, he's traveling about 5 miles per second around the Earth, which keeps

him in orbit. His travels at the same rate that the Earth is curving away from him. To simulate artificial gravity, he would need to be in a rotating space station.

17. Maxwell's equations predict the existence of EM waves (light) going at speed c… but with respect to what? Relative to what? Speed c is relative to all observers.

