Year 6, Lesson 1: I will go the distance!

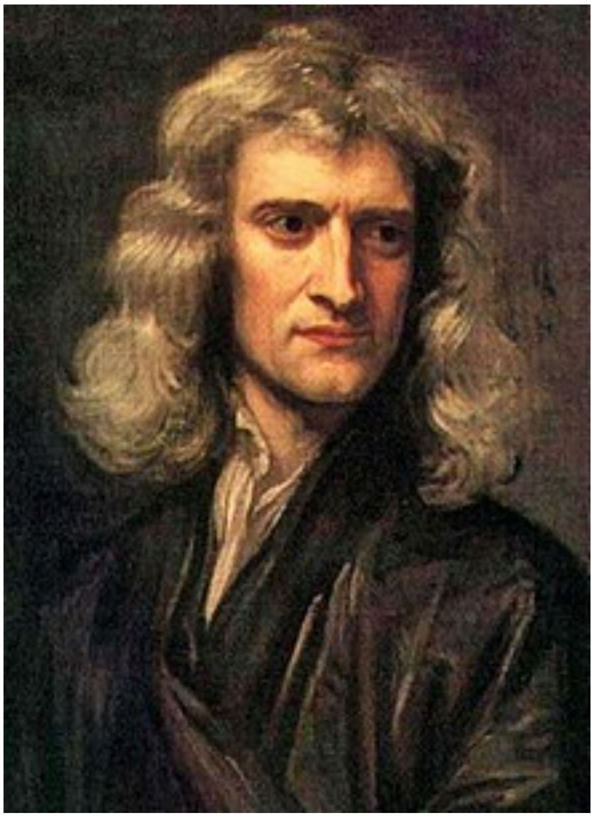
Welcome back to Astronomy! I congratulate you all on having achieved an average grade of at least 80% on your O.W.L. exams. But I want to warn you that, now that you are N.E.W.T. students, the material in the lessons will be more advanced, including physics in Year 6 and some mathematics in Year 7. I don't think I need to repeat what I and my predecessors have said about the weights attached to each component of the assignments, because they have not changed from previous years. The only change from previous years is that the assignments, like the lessons, will be more challenging.

Here is the syllabus of Year 6.

Year Six: Space Oddities		
Lesson #	Title/Topic(s)	Details/Notes
1	**I Will Go the Distance!**	Gravity, dimensions of space, relativity
2	**Electromagnetism**	Spectroscopy, Electric and Magnetic Fields
3	**Back in Black**	Black holes, Dark energy, Dark matter
4	**Asteroids, Meteors, Comets Part One**	Differentiating Asteroids, Meteors, Comets, magical relevance
5	**Asteroids, Meteors, Comets Part Two**	Important events, Halley's comet, Meteor showers
6	**It's Falling From the Sky**	Space debris, space rock, uses
7	**Reproducing Space on Earth**	Shooting stars, Orreys, Mirroring charms
8	**Space Travel**	The great wizarding space race
9	**Day-to-Day Astronomy**	Calendar making based on astronomical bodies

Gravity

The universal law of gravitation was one of the many discoveries made by the polymath Sir Isaac Newton (1643-1727), an English mathematician, physicist, astronomer and alchemist (yes, he was a wizard, as those who are studying Alchemy should know).



His biography, at least the part of it of which Muggles are aware, can be found on the web page https://en.wikipedia.org/wiki/Isaac_Newton , from which the above photograph was copied. But before discussing the universal law of gravitation, I want to present a brief history of the events leading up to this discovery.

The planets visible to the naked eye follow a rather complicated path in the sky with respect to the fixed stars. The ancient Greek astronomer Claudius Ptolemy thought that Earth was the centre of the universe and that every celestial body must move in a circle; so he created a model of the solar system in which the sun, the stars and all the planets revolve around the earth in circles, but the complicated path of the planets had to be explained by having them move in smaller circles, called epicycles, around a point that revolves around Earth in a circle.

Now, who do you think was the first one to suggest that Earth and all the other planets revolve around the sun? Did you say Copernicus? If you did, you are in the majority, but you are wrong. It was Aristarchus of Samos, an ancient Greek mathematician and astronomer who lived in the 3^{rd} century B.C.E. His reasoning was that since the sun is bigger than Earth, the sun would influence Earth rather than the other way around. We know now what that influence is – gravity – which he couldn't have known, but he did anticipate it, which is astonishing. His theory was condemned as impious by the Stoic philosopher Cleanthes, after which he stopped mentioning it. Historians of astronomy know about Aristarchus' theory through the writings of that greatest of all ancient Greek scientists, Archimedes.

Nicolaus Copernicus (1473-1543) resurrected Aristarchus's theory and gave Aristarchus credit for it. Galileo Galilei (1564-1642) found evidence to confirm Copernicus' theory – with his telesope he discovered the phases of Venus – and he published his support of the Copernican theory in a book which so angered the Roman Catholic Church that in 1633 they forced him under threat of torture to recant his views and condemned him to spend the rest of his life in house arrest. The Church finally admitted that he was right – in 1992.

Like Ptolemy, Copernicus believed that all celestial bodies travel in a circle; so, like Ptolemy, he had to introduce epicycles into the orbits of the planets. It was Johannes Kepler who found the fix. After studying the careful observations, made by Tycho Brahe, of the paths of the planets with respect to the fixed stars, Kepler concluded, among other things, that a planet in fact travels in an ellipse – a flattened circle. See the web page https://en.wikipedia.org/wiki/Kepler-s_laws_of_planetary_motion
for Kepler's three laws and a picture of an ellipse. Now the paths of the planets could be explained without resorting to epicycles, but nobody knew what made them move that way – that is, until Isaac Newton came along.

Newton had already discovered three laws of motion. The first law says that a body that's not moving will continue not moving and a body that is moving will continue to move at the same speed and in a straight line unless a force is applied to it. He concluded that an unsupported object falls to the ground because the Earth applies a force to it – that is, the Earth attracts the object. Similarly, the moon revolves around the Earth instead of moving away in a straight line because the Earth attracts the moon too. Newton's third law of motion says that when you apply a force to an object, it applies the same amount of force in the opposite direction to you, which you can feel when you try to throw a heavy stone. Finally, his second law says that when you apply a force to an object, you make it accelerate – that is, change speed or direction or both – and the acceleration is equal to the force you apply divided by the mass of the object. Combining these laws with Kepler's laws of motion, Newton came up with his law of universal gravitation:

Any two bodies attract each other with a force that is equal to the product of the masses of the two bodies divided by the square of the distance between them and multiplied by a constant.

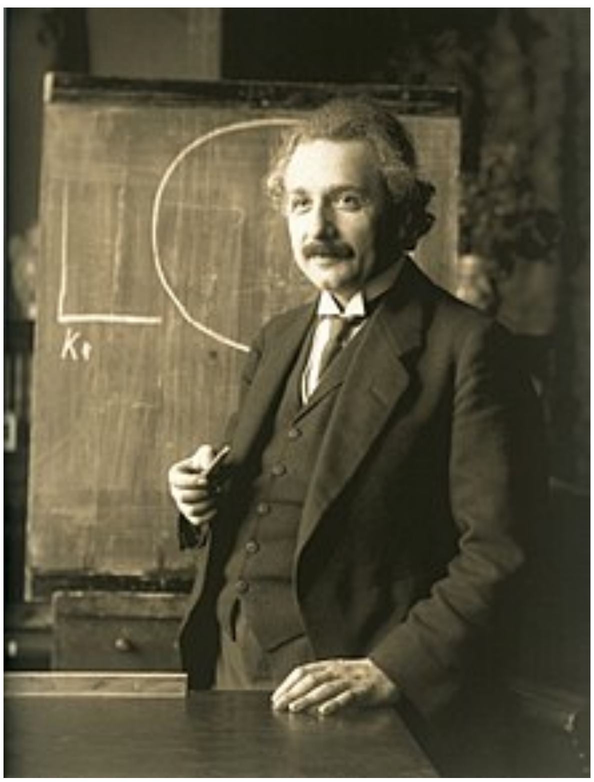
See the web site http://www.physicsclassroom.com/class/circles/Lesson-3/Newton-s-Law-of-Universal-Gravitation for details.

What is a square, you might ask? Well, you'll have to know some mathematics in Year 7 of this course, but for now I'll tell you: the square of a number is that number multiplied by itself. For example, the square of 3 is 3 times 3, which is 9. If you were three times as far from the centre of the Earth as you are now, you would weigh only 1/9 of what you weigh now.

Any star, including the sun, attracts the nearby planets, making them revolve around the star instead of floating off into space. But the planets attract the star too, making it move a bit. A distant star's side-to-side motion is too small for astronomers to detect, but even a very slight motion towards and away from us can be detected using the Doppler effect (see Lesson 2), which is one way in which we can find planets orbiting other stars.

Relativity

Newton's law of universal gravitation is accurate enough for all calculations used in space travel, but for very strong gravity it's only an approximation. It was left to the German-born theoretical physicist Albert Einstein (1879-1955) to modify Newton's law so that it is accurate for gravity no matter how strong in his general theory of relativity, which he formulated in 1916. A biography of Einstein can be found on the web page https://en.wikipedia.org/wiki/Albert_Einstein from which the photograph below, taken in 1921, was copied.

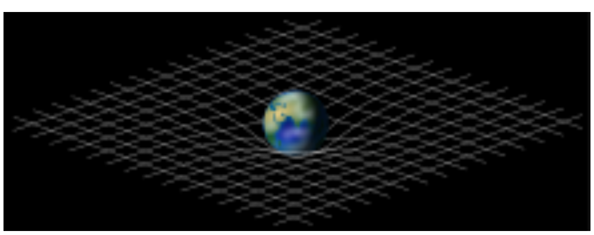


Before getting into the general theory, I want to discuss his special theory of relativity, which he formulated in 1905. Before then, people used to believe that there was such a thing as absolute space, which was filled with a substance called ether. In 1987, Michelson and Morley tried to measure the speed at which Earth travelled through the ether (see the web page https://en.wikipedia.org/wiki/Michelson-Morley_experiment) at different times of the year and discovered that no such motion could be found no matter what time of the year it was. Einstein concluded from these observations that there is no such thing as absolute space – there is only motion of an object relative to a given observer, whence the name relativity, as long as the object being observed is moving in a straight line at a constant speed relative to the observer - and that the speed of light in a vacuum is the same for all observers regardless of the motion of the light source. He deduced several interesting consequences (see the web page https://en.wikipedia.org/wiki/Special_relativity), among them that nothing can move faster than light, that time seems to slow down on an object moving fast with respect to an observer so that if you travel fast enough away from Earth and back, you age slower than an observer on Earth, that an object moving with respect to an observer appears to be both shorter and more massive than it appears to an observer moving with the object, and that mass and energy can be converted into each other via the formula

energy = mass times the square of the speed of light in a vacuum.

The speed of light is very great – about 186000 miles a second – so you can get a lot of energy out of a small amount of mass. This made it possible to create an atomic bomb, which converts an isotope of uranium or plutonium into lighter elements that together are less massive than the uranium or plutonium, and later a hydrogen bomb, which fuses two atoms of deuterium, an isotope of hydrogen, into an atom of helium, which is less massive than the two atoms of deuterium. This fusion is the process by which all stars, including the sun, produces energy.

But then, in 1916, Einstein generalized his theory to include accelerated motion, starting from the idea that gravity and acceleration are indistinguishable – that is, if you're in an elevator in space and can't see out of it, you can't tell whether it's gravity or the elevator accelerating upwards that keeps you from floating off the floor of the elevator. He concluded that a massive body curves the space around it and that other bodies follow the curve around the massive body the way a heavy ball deforms a trampoline making lighter balls revolve around it instead of moving in a straight line – see the web page https://en.wikipedia.org/wiki/General_relativity from which the picture below was copied. This picture is a three-dimensional analogue of what actually happens. Another consequence of the theory of special relativity is that time can be considered a fourth dimension in what is called spacetime (see https://en.wikipedia.org/wiki/Spacetime) in which bodies move. A massive body warps spacetime so that less massive bodies, when moving in spacetime, orbit the massive body – and that's what gravity is, according to Einstein.



Another consequence is that a massive body makes light bend around it, which was verified by observing the displacement of the image of a star during a total eclipse of the sun, and is responsible for gravitational lensing: a distant galaxy can appear brighter if there is nearer galaxy between the distant one and Earth. Another consequence is that time slows down near a massive object; so if you're near a massive object – not in orbit around it but standing still where you can feel tremendous gravitational force – you'll age slower than someone who's farther away from it. It turns out that this effect, as small as it is near Earth, must be taken into consideration in sychronizing a GPS system, because time goes faster on the satellite emitting the signal than it does on Earth.

Dimensions of space

Now how big is the universe, or is it infinite? Well, it used to be argued that the universe must be finite because otherwise no matter which direction you look, there will be a star somewhere in your line of sight, making the night sky bright instead of dark, or at least as dark as light pollution will allow. The problem with this idea is that space is expanding – this was discovered by Edwin Hubble – so when you get far enough away, everything is moving away from you as fast as the speed of light, and you can't see anything beyond that distance because the galaxies there are moving away from you faster than the speed of light, and that's why the night sky would still be dark even if the universe is infinite. This seems to contradict one of the conclusions of Einstein's special theory of relativity – that nothing can move faster than light. But that conclusion only holds for local motion. It doesn't hold for very distant objects because the objects aren't moving through space; rather, space itself is expanding. So we can't ever know whether the universe is finite or infinite.

But we can measure the size of the observable universe – that is, the part of the universe that's close enough that the light from the retreating galaxies can reach us. It's about 46.5 billion light years (a light year is the distance that light can travel in a year, about 6 trillion miles). See the web page https://en.wikipedia.org/wiki/Observable_universe . The observable universe isn't infinite, but it's pretty big; so if you want to go the distance, you'll have to travel for a long time!

Assignment (an essay).

This assignment will require a lot of searching on the internet. Links to web pages from which information about some of the people and events mentioned in this lesson are included, but not all. You'll need to find the dates of each of the events and the birth and death dates (years) of each of the people (centuries will do for the ancient Greeks). Make a time line of each of the dates in chronological order, giving a one-line description of each event or birth date or death date after the year. Cite all your sources.

Your grade will depend on the number of dates you put on your time line and the correctness of the chronological order. Up to two extra credit points will be awarded for drawing your time line artistically. Up to three extra credit points will be awarded for adding to your time line other verifications of Einstein's general theory of relativity aside from the one mentioned in the lesson.

Year 6, Lesson 2: Electromagnetism

Spectroscopy

White light is a mixture of lights of all colours and it can be split into its constituent colours. You must have seen it done – many times (see the picture below).

Droplets of water in the air can split sunlight into colours. So can a glass prism (see the picture below, which was copied from the web page https://en.wikipedia.org/wiki/Visible_spectrum).

Isaac Newton shone a narrow beam of sunlight through a glass prism, which split the white light into its colours, which he called a spectrum. The colours blend smoothly into each other, but they're generally grouped into six or seven colour names: red, orange, yellow, green, blue, (indigo), violet. Then he passed the coloured light through another prism turned upside down with respect to the one in the picture, and white light came out the other side.

How does it work? Light travels slower in water than it does in air or in a vacuum, and it travels even slower in glass. The ratio between the speed of light in a vacuum and the speed of light in a given transparent material is called the refractive index of that material. When it passes from air into glass at an angle, it changes direction to be closer to a line perpendicular to the boundary between the air and the glass. Then, when it passes from glass back into air, it changes direction again to be farther from a line perpendicular to the second boundary. As you can see from the picture, the coloured light comes out in a different direction from the white light. But the refractive index is different for different colours of light. Red light travels the fastest through glass; so it's bent the least. Violet light travels slowest through glass; so it's bent the most. Light of the other colours travel at intermediate speeds. And that's how a triangular prism splits white light into its colours. A droplet of water does the same thing, but the light has to get reflected from the back of the droplet. Look up on the internet how a rainbow is made.

If you look at a bright light (NOT the sun, if you value your eyesight) through a cheap telescope, you'll notice that unless the light is in the centre of your field of view, it will have colour fringes on both sides, with red on the side nearer the centre of the field of view and violet on the other side. That's because every part of the lens except for the centre acts like a prism. This defect is called chromatic aberration. More expensive Muggle telescopes correct this defect by using two or even three lenses instead of one. Each lens is made of a different material, which separate light into its colours by a different amount. With two lenses, they can arrange that red and green light stay together – they call that kind of telescope achromatic. With three lenses, they can arrange that blue light too stays together with red and green, and the other colours separate very little. That kind of telescope is called apochromatic, and it's even more expensive. A magical telescope – for example, a von Rheticus telescope – corrects chromatic aberration much more cheaply – by magically adjusting the index of refraction of the lens to be the same for all colours.

Spectroscopy is the study of objects based on the spectrum of colour they emit, absorb or reflect. With spectroscopy one can tell the surface temperature of a star and what gases its made of, what gases the atmosphere of a planet is made of, and whether a celestial body is moving towards us or away from us and how fast, which enabled Hubble to determine that the universe is expanding and is one way of enabling modern-day astronomers to detect planets orbiting other stars. All this will be explained in later sections of this lesson.

Now light acts like waves in water, but what is light waves of? People used to think that light was waves in ether, which they called luminiferous aether, but we now know that no such thing exists. James Clerk Maxwell discovered that in fact, light is really electromagnetic waves; so to continue our study of light, the next thing we have to discuss is electromagnetism.

Electromagnetism

You must have learned in school that an atom consists of a nucleus and electrons revolving around the nucleus. An electron is a tiny little particle with a negative charge. The nucleus consists of protons, which have a positive charge, and neutrons, which have no charge. In an atom there are the same number of electrons as protons; so the atom itself is electrically neutral. If there are more or fewer electrons than protons, then instead of an atom you have an ion. An object that has more electrons than protons in all its atoms is negatively charged and an object that has more protons than electrons is positively charged.

Two negatively charged objects repel each other and two positively charged objects also repel each other. A positively charged object and a negatively charged object attract each other. The force of attraction or repulsion obeys the same law as the universal law of gravitation: it is equal to the product of the two charges divided by the square of the distance between them and multiplied by a constant. In this way, an object that is charged either positively or negatively creates an electric field, in which objects with the opposite charge are attracted and objects with the same charge are repelled. In the classical model, the electrons revolve about the nucleus the way planets revolve around a star; the attraction between the nucleus and the electrons keep the electrons from flying away from the nucleus and the momentum of the electrons keep them from flying into the nucleus.

Now what is it that keeps two solid objects from merging with each other? Since electrons revolve around the nucleus, the closest particles to the surface of each object are the electrons, not the nuclei. When two objects touch each other, the electrons at the surface of one object and the electrons at the surface of the other object repel each other more than the protons of each object attract the electrons of the other object; so the two objects repel each other as long as they are in contact, which keeps them from merging unless you apply enough pressure (force per unit of area) to force one object into the other one.

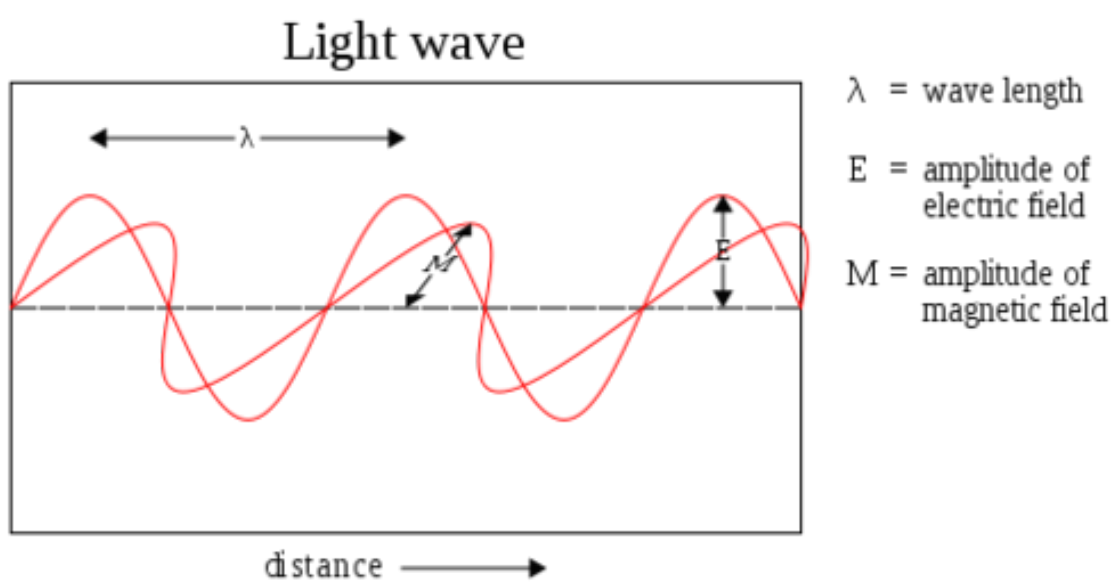
If you rub two objects together, one of them may give some of its electrons to the other one; so the donor becomes positively charged and the recipient becomes negatively charged, and then the two objects will attract each other. Either one will be attracted to an electrically neutral object, because a negatively charged object will push the electrons in the neutral object away and make its nearby surface electrically positive, and a positively charged object will pull the electrons in the neutral object closer and make its nearby surface electrically negative. If you rub your feet on a rug in a dry room, you will become charged, and if you then touch something metallic, you will see a spark as the electrons jump either from you to the metal or from the metal to you, heating up the air they pass through, and you will hear a little tick and feel a shock. Lightning is just a big electric spark, making a big noise called thunder and giving a possibly fatal shock to anyone it hits.

What I just described is called static electricity – that is, electricity that doesn't move. An electric current in a wire is made of free electrons moving along the wire. If they always move in the same direction, which happens when a battery is part of the circuit containing the wire, then it's called direct current. If they keep changing direction, like the electricity in your home, then it's called alternating current. Either direct current or alternating current can make a light bulb shine because electricity heats up anything it passes through, but only an alternating current can make things move because for reasons that will become clear once we've discussed magnetism.

A magnet has two poles, a north pole and a south pole. Two north poles repel each other and two south poles repel each other, but a north pole and a south pole attract each other, and the force is equal to the product of the strengths of the two poles divided by the square of the distance between them and multiplied by a constant. There's no such thing as a north pole by itself or a south pole by itself – there's just a magnet with a north pole and a south pole. A magnet creates a magnetic field in which another magnet will realign so that the two opposite poles, one of each magnet, are nearest each other, and then the magnets will attract each other. The Earth has a magnetic north pole and a magnetic south pole, which are close to the geographical north pole and south pole, respectively. A compass needle is a magnet that is free to spin horizontally; so its south pole will always point towards the Earth's north magnetic pole. An object that isn't magnetized but is made out of iron will be attracted to either pole of a magnet because the pole temporarily magnetizes the object to make the nearest part of the object the opposite pole.

It turns out that electricity and magnetism are closely related. An electric current running through a wire creates a magnetic field around the wire, and moving a wire though a magnetic field produces a current in the wire. An electron revolving around the nucleus of an atom also creates a magnetic field. In some substances, like iron, the atoms can be aligned so that the majority of the electrons revolve in the same direction, and that's how a permanent magnet is made. An alternating current in a wire wound around an iron core will create a magnetic field that keeps changing direction, which can power a motor, and that's how the electricity in your home powers your appliances.

Now light consist of two oscillating waves, one magnetic and the other electric, as illustrated by the picture below

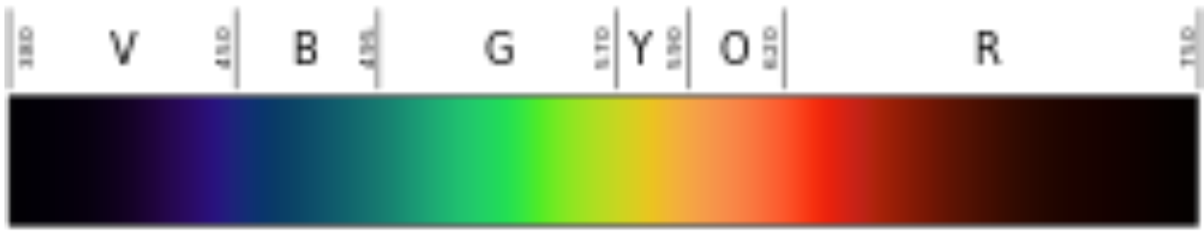


which was copied from this web page :

https://www.khanacademy.org/science/physics/light-waves/introduction-to-light-waves/a/light-and-the-electromagnetic-spectrum

Read that whole web page. It has material that will be discussed later in this lesson.

Here is what the spectrum looks like:



and here is a table of the range of wavelengths of each colour of light in nanometers (billionths of a meter).

Color	Wavelength	Frequency	Photon energy
Violet	380–450 nm	668–789 THz	2.75–3.26 eV
Blue	450–495 nm	606–668 THz	2.50–2.75 eV
Green	495–570 nm	526–606 THz	2.17–2.50 eV
Yellow	570–590 nm	508–526 THz	2.10–2.17 eV
Orange	590–620 nm	484–508 THz	2.00–2.10 eV
Red	620–750 nm	400–484 THz	1.65–2.00 eV

The frequency in terahertz (trillions of cycles per second) is found by dividing the speed of light (about 300000 kilometers per second) by the wavelength. The last column will be explained in the next section.

These two pictures were copied from the web page
https://en.wikipedia.org/wiki/Visible_spectrum

Yes, VISIBLE spectrum. These are just the wavelengths of electromagetic waves that we can see. Waves longer than those of red light and up to about 1 millimeter are infrared waves, which can't be seen but can be felt as heat. Microwaves range from 1 millimeter to 1 meter, and any wave longer than that is called a radio wave. Ultraviolet light waves are shorter than those of violet light and down to about 10 nanometers. They're the ones that give you a suntan, or a sunburn if you're exposed to them for too long. Xrays range from 10 nanometers to 0.01 nanometers. They're the ones that pass through skin and show your internal organs. Any wave shorter than an xray is called a gamma ray.

Modern spectroscopes don't use a prism. Instead they use a diffraction grating. To introduce a diffraction grating I first need to discuss two more properties of waves – interference and diffraction. These topics are discussed in full on the web page
https://www.khanacademy.org/test-prep/mcat/physical-processes/light-and-electromagnetic-radiation-questions/a/diffraction-and-constructive-and-destructive-interference

so my discussion will be brief. Suppose waves from two different sources meet in a point. If the peak (the highest point) of one wave hits the point at the same time as the peak of the other wave and the trough (the lowest point) of one wave hits the point at the same time as the trough of the other wave, then the height of the peak of the combined wave will be the sum of the heights of the two peaks and the depth of the trough of the combined wave will be the sum of the depths of the two troughs; so the combined wave will be stronger than either of the two waves. This is called constructive interference. On the other hand, if the peak of each wave hits the point at the same time as the trough of the other one, then the strength of combined wave will be the difference between the strengths of the two waves, and if the two waves are equally strong, then the combined wave will have no strength at all. This is called destructive interference. To simulate this effect, fill up a large container with water and move your index finger of both hands up and down in the water at the same speed and watch the waves.

Now put an obstacle in the container, make waves on one side of the obstacle and look at the water on the other side. You will see that the waves have bent around the obstacle. That's called diffreaction, and it happens because the edges of the obstacle act as sources of waves. You can also see interference between the waves made by the two edges. The interference pattern depends upon the wavelength, and a diffraction grating uses this to make a spectrum. Read the whole web site for more information.

Here's another way to observe diffraction. Bend your index finger to make a tiny hole and look at something bright through the hole. You will see dark parts – that's the interference pattern made by diffraction. The smaller the hole is, the darker the dark parts get and the more of the hole they cover, making the image less and less clear. That's what limits the resolution of a telescope. The bigger the lens (or mirror) of a telescope is, the better the resolution will be. That's why Muggle astronomers want bigger and bigger telescopes even if they don't need the light gathering power of big telescopes. Another way that Muggles solve the diffraction is to set up two telescopes so that the diffraction from both of them interfere destructively. This combination of telescopes is called an inteferometer, and its resolution is the same as that of a single telescope whose lens or mirror size is the distance between the two telescopes.   A telescope with a big lens or mirror is expensive and so is an interferometer.

Now you've learned in Year 1 that a von Rheticus telescope is small enough to fit into a pocket but it can see more clearly than a Muggle telescope of the same size. How does it work? The far end of the tube is enchanted to make the waves it creates go away from the telescope rather than through the lens. Now you've learned in Transfiguration that to change the atoms and molecules of an object, a spellcaster has to know what the desired atoms and molecules look like. To make his telescope, von Rheticus had to know about chromatic aberration and diffraction. A good witch or wizard needs to know what Muggle scientists have discovered, and that's why I'm putting so much Muggle information in my lessons and suggesting that you read more of it on the internet – in fact, forcing you to do so (see the assignment). The Khan Academy is an excellent web site, which will teach you everything you need to know – except, of course, magic.

Wave-particle duality

Newton thought that light consisted of a stream of particles, which he called corpuscles. He was partly right. Although light does act like a wave, it also acts like a stream of particles, which are now called photons. Look at the third column of the table in the previous section. It gives the energy of the photons of light various colours. The energy is measured in electron volts, which you can look up if you want to. The important thing to observe here is that the shorter the wavelength is, the more energetic the photon is. The product of the wavelength and the photon energy is a constant, called Planck's constant, which you can also look up.

The higher the surface temperature of a star is, the stronger the waves of every length it will emit, but the strongest waves will be shorter the hotter the star is because short waves correspond to more energetic photons. And that's why the coolest stars are red and the hottest stars are blue; so you can tell the surface temperature of a star by looking at its spectrum.

I also mentioned that you can tell what gases a star is made of and what gases the atmosphere of a planet is made of by looking at the spectrum of a star. To explain this, I need to refine the classical description of an atom, in which the electrons revolve around the nucleus the way planets revolve around a star. If that were really how an atom works, the electrons would emit radiation as they revolved, sapping their energy and sending them crashing into the nucleus. Instead, an electron can be in one of several orbits, each with a different energy level – the farther the electron is from the nucleus, the higher the energy level is. If an electron drops from a higher energy level to a lower one, it emits a photon whose energy is the difference between the two energy levels. Each atom or molecule has its own set of photons it can emit, and together they constitute the emission spectrum of that element or compound. In a spectroscope, you can see the emission spectrum of a star as a series of bright lines, which combines the emission spectra of all the gases in the star, and that's how you can tell what gases the star is made of. Now suppose that an electron gets hit by a photon whose energy is the difference between the energy level the electron is in and some higher energy level for the same atom. Then the electron will jump to the higher energy level and the photon will be absorbed. The absorption spectrum of an atom or molecule is the same as the emission spectrum except that in the spectroscope you see it as a series of dark lines. When a planet passes in front of a star, the atmosphere of the planet absorbs some of the star's photons, and that's how you can tell what gases the planet's atmosphere is made of.

That information is a very sketchy outline of the beginning of the quantum theory, to which Einstein contributed. Further developments of the quantum theory made a description of the world of the very small weirder and weirder. For a long time, Einstein refused to believe in these later developments. When the evidence became indisputable, he had to accept it, but he still didn't like it. One thing that bothered him was that quantum theory is incompatible with his general theory of relativity. He spent the last thirty years of his life vainly trying to reconcile the two theories. Modern physicists have made other such attempts, including string theory, none of which are testable; so the problem remains unsolved to this day.

I also mentioned that spectroscopy can be used to tell whether a celestial body is moving towards us or away from us and how fast. To explain this I need to discuss one more wave property of light – the Doppler effect.

The Doppler effect

Did you ever notice that the pitch of a sound made by a moving object gets lower as the object passes you, and that if you're moving, the pitch of a sound made by a stationary object gets lower as you pass it? This is the Doppler effect. When you're approaching an object or it's approaching you, the crests of the sound waves it emits reach you more often, making the pitch higher. When you're moving away from an object or it's moving away from you, the crests of the sound waves it emits reach you less often, making the pitch lower. See the web page http://www.physicsclassroom.com/class/waves/Lesson-3/The-Doppler-Effect
for a more detailed explanation and some illustrative diagrams.

The same thing happens with light, except that instead of a higher pitch, the light waves get shifted to the blue end of the spectrum, and instead of a lower pitch, the light waves get shifted to the red end of the spectrum. When a planet revolves around a star, it makes the star wobble, so that it sometimes it moves towards you and sometimes it moves away from you. The emission lines of the star get shifted slightly towards the blue end when the star moves towards you and towards the red end when the star moves away from you, and that's one of the ways in which astronomers can detect planets revolving around stars other than the sun. Edwin Hubble observed that the farther away a galaxy is, the more its emission spectrum shifts towards the red, and that's how he was able to conclude that the universe is expanding. This topic will be discussed in greater detail in the next lesson. I've already bored you enough in this one.

Assignment (an essay)

Research two of the following three topics on the internet and express in your own words what you find out.

Topic 1: How do droplets of water make a rainbow?

Topic 2: How does a diffraction grating produce a spectrum?

Topic 3: What does the world of the very small look like according to the latest developments in quantum theory?

There is no word limit. Your grade will depend upon the amount of correct detail you give for each topic. If you do all three topics, the best two will count for your numerical grade and the other one for extra credit.