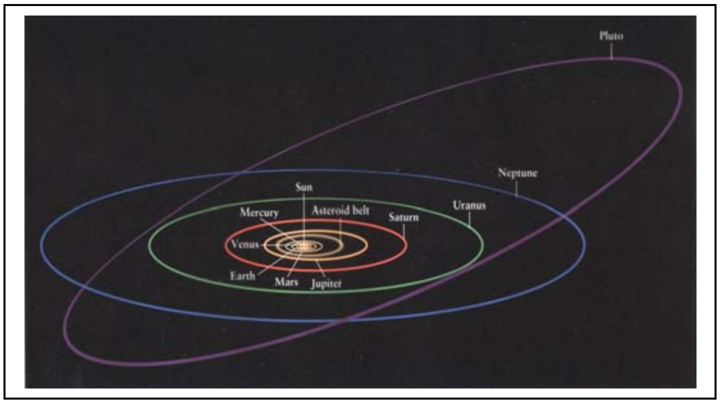
How Big is Our Solar System?



Our solar system is so big it is almost impossible to imagine its size if you use ordinary units like feet or miles. The distance from Earth to the Sun is 93 million miles (149 million kilometers), but the distance to the farthest planet Neptune is nearly 3 billion miles (4.5 billion kilometers). Compare this to the farthest distance you can walk in one full day (70 miles) or that the International Space Station travels in 24 hours (400,000 miles).

The best way to appreciate the size of our solar system is by creating a scaled model of it that shows how far from the sun the eight planets are located. Astronomers use the distance between Earth and sun, which is 93 million miles, as a new unit of measure called the Astronomical Unit. It is defined to be exactly 1.00 for the Earth-Sun orbit distance, and we call this distance 1.00 AUs.

Problem 1 - The table below gives the distance from the Sun of the eight planets in our solar system. By setting up a simple proportion, convert the stated distances, which are given in millions of kilometers, into their equivalent AUs, and fill-in the last column of the table.

Planet	Distance to the Sun in millions of kilometers	Distance to the Sun in Astronomical Units
Mercury	57	
Venus	108	
Earth	149	
Mars	228	
Jupiter	780	
Saturn	1437	
Uranus	2871	
Neptune	4530	

Problem 2 – Suppose you wanted to build a scale model of our solar system so that the orbit of Neptune was located 10 feet from the yellow ball that represents the sun. How far from the yellow ball, in inches, would you place the orbit of Jupiter?

Answer Key

Problem 1 - The table below gives the distance from the Sun of the eight planets in our solar system. By setting up a simple proportion, convert the stated distances, which are given in millions of kilometers, into their equivalent AUs, and fill-in the last column of the table.

Answer: In the case of Mercury, the proportion you would write would be

$$\frac{149 \text{ million km}}{1 \text{ AU}} = \frac{57 \text{ million km}}{X} \quad \text{then } X = 1 \text{ AU} \times (57/149) = 0.38$$

Planet	Distance to the Sun in millions of kilometers	Distance to the Sun in Astronomical Units
Mercury	57	0.38
Venus	108	0.72
Earth	149	1.00
Mars	228	1.52
Jupiter	780	5.20
Saturn	1437	9.58
Uranus	2871	19.14
Neptune	4530	30.20

Problem 2 – Suppose you wanted to build a scale model of our solar system so that the orbit of Neptune was located 10 feet from the yellow ball that represents the sun. How far from the yellow ball, in inches, would you place the orbit of Jupiter?

Answer: The proportion would be written as:

$$\frac{30.20 \text{ AU}}{10 \text{ feet}} = \frac{5.2 \text{ AU}}{X} \quad \text{then } X = 10 \text{ feet} \times (5.2/30.2) \quad \text{so } X = \mathbf{1.72 \text{ feet}}$$

Since 1 foot = 12 inches, the unit conversion is written as

$$1.72 \text{ feet} \times \frac{12 \text{ inches}}{1 \text{ foot}} = \mathbf{20.64 \text{ inches}}.$$

Visiting the Planets at the Speed of Light!

The fastest way to get from place to place in our solar system is to travel at the speed of light, which is 300,000 km/sec (670 million miles per hour!). Unfortunately, only radio waves and other forms of electromagnetic radiation can travel exactly this fast.

When NASA sends spacecraft to visit the planets, scientists and engineers have to keep in radio contact with the spacecraft to gather scientific data. But the solar system is so vast that it takes quite a bit of time for the radio signals to travel out from Earth and back.

Problem 1 – Earth has a radius of 6378 kilometers. What is the circumference of Earth to the nearest kilometer?

Problem 2 – At the speed of light, how long would it take for a radio signal to travel once around Earth?

Problem 3 – The Moon is located 380,000 kilometers from Earth. During the Apollo-11 mission in 1969, engineers on Earth would communicate with the astronauts walking on the lunar surface. From the time they asked a question, how long did they have to wait to get a reply from the astronauts?

Problem 4 – In the table below, fill in the one-way travel time from the sun to each of the planets. Use that fact that the travel time from the Sun to Earth is 8 ½ minutes. Give your answer to the nearest tenth, in units of minutes or hours, whichever is the most convenient unit.

Planet	Distance from Sun in Astronomical Units	Light Travel Time
Mercury	0.38	
Venus	0.72	
Earth	1.00	8.5 minutes
Mars	1.52	
Jupiter	5.20	
Saturn	9.58	
Uranus	19.14	
Neptune	30.20	

Problem 1 – Earth has a radius of 6378 kilometers. What is the circumference of Earth to the nearest kilometer?

Answer: $C = 2 \pi R$ so $C = 2 \times 3.141 \times (6378 \text{ km})$ = **40,067 km.**

Problem 2 – At the speed of light, how long would it take for a radio signal to travel once around Earth?

Answer: Time = distance/speed so
Time = 40,067/300,000 = **0.13 seconds. This is about 1/7 of a second**.

Problem 3 – The Moon is located 380,000 kilometers from Earth. During the Apollo-11 mission in 1969, engineers on Earth would communicate with the astronauts walking on the lunar surface. From the time they asked a question, how long did they have to wait to get a reply from the astronauts?

Answer: From the proportion:

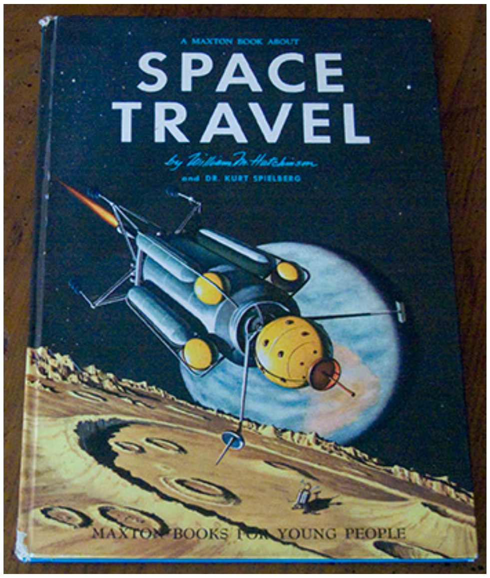
$$\frac{0.13 \text{ seconds}}{40067 \text{ km}} = \frac{X}{380000 \text{ km}}$$ we have X = (380000/40067) x 0.13 = 1.23 seconds.

This is the one-way time for the signal to get to the moon from Earth, so the round-trip time is twice this or **2.46 seconds**.

Problem 4 – In the table below, fill in the one-way travel time from the sun to each of the planets. Use that fact that the travel time from the Sun to Earth is 8 ½ minutes. Give your answer to the nearest tenth, in units of minutes or hours, whichever is the most convenient unit.

Answer: Use simple proportions based on 8.5 minutes of time = 1.00 AU of distance.

Planet	Distance from Sun in Astronomical Units	Light Travel Time
Mercury	0.38	3.2 minutes
Venus	0.72	6.1 minutes
Earth	1.00	8.5 minutes
Mars	1.52	12.9 minutes
Jupiter	5.20	44.2 minutes
Saturn	9.58	1.4 hours
Uranus	19.14	2.7 hours
Neptune	30.20	4.3 hours



Most science fiction stories often have spaceships with powerful, or exotic, rockets that can let space travelers visit the distant planets in less than a day's journey. The sad thing is that we are not quite there in the Real World. This is because our solar system is so vast, and our rockets can't produce quite enough speed to make journeys short.

NASA has been working on this problem for over 50 years and has come up with many possible solutions. Each one is more expensive than just using ordinary fuels and engines like the ones used on most rockets!

Problem 1 – The entire International Space Station orbits Earth at a speed of 28,000 kilometers per hour (17,000 mph). At this speed, how many days would it take to travel to the sun from Earth, located at a distance of 149 million kilometers?

Problem 2 – The planet Neptune is located 4.5 billion kilometers from Earth. How many years would it take a rocket traveling at the speed of the International Space Station to make this journey?

Problem 3 – The fastest unmanned spacecraft, Helios-2, traveled at a speed of 253,000 km/hr. In the table below, use proportional math to fill in the travel times from the sun to each planet traveling at the speed of Helios-2. Give your answers to the nearest tenth in appropriate units of days or years.

Planet	Distance in millions of kilometers	Time
Mercury	57	
Venus	108	
Earth	149	
Mars	228	
Jupiter	780	
Saturn	1437	
Uranus	2871	
Neptune	4530	

Problem 1 – The entire International Space Station orbits Earth at a speed of 28,000 kilometers per hour (17,000 mph). At this speed, how many days would it take to travel to the sun from Earth, located at a distance of 149 million kilometers?

Answer: Time = Distance/speed so
Time = 149,000,000 km/ 28,000
= 5321 hours or **222 days**.

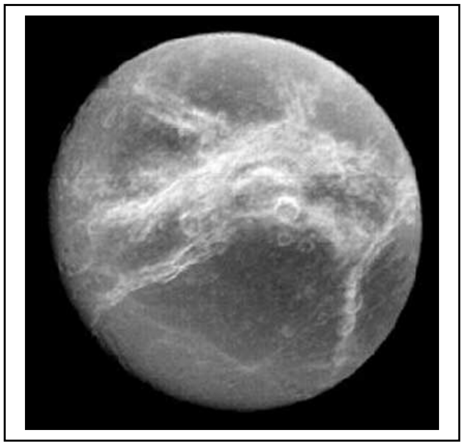
Problem 2 – The planet Neptune is located 4.5 billion kilometers from Earth. How many years would it take a rocket traveling at the speed of the International Space Station to make this journey?

Answer: Time = 4,500,000,000 km / 28,000 km/h
= 160714 hours or 6696 days or **18.3 years**.

Problem 3 – The fastest unmanned spacecraft, Helios-2, traveled at a speed of 253,000 km/hr. In the table below, use proportional math to fill in the travel times from the sun to each planet traveling at the speed of Helios-2. Give your answers to the nearest tenth in appropriate units of days or years.

Planet	Distance in millions of kilometers	Time
Mercury	57	9.4 days
Venus	108	17.8 days
Earth	149	24.5 days
Mars	228	37.5 days
Jupiter	780	128.5 days
Saturn	1437	236.7 days
Uranus	2871	1.3 years
Neptune	4530	2.0 years

A Matter of Timing



Astronomers who study planets and their satellites often have to work out how often satellites or planets 'line up' in various ways, especially when they are closest together in space.

Figure shows the satellite Dione (Courtesy: NASA/Cassini)

Problem 1 – The two satellites of Tethys and Dione follow circular orbits around Jupiter. Tethys takes about 2 days for one complete orbit while Dione takes about 3 days. If the two satellites started out closest together on July 1, 2008, how many days later will they once again be at 'opposition' with one another?

A) Find the Least Common Multiple between the orbit periods.

B) Draw two concentric circles and work the solution out graphically.

C) What is the relationship between your answer to A and B?

Problem 2 - Two planets have orbit periods of 3 years and 5 years. How long will it take them to return to the same locations that they started at?

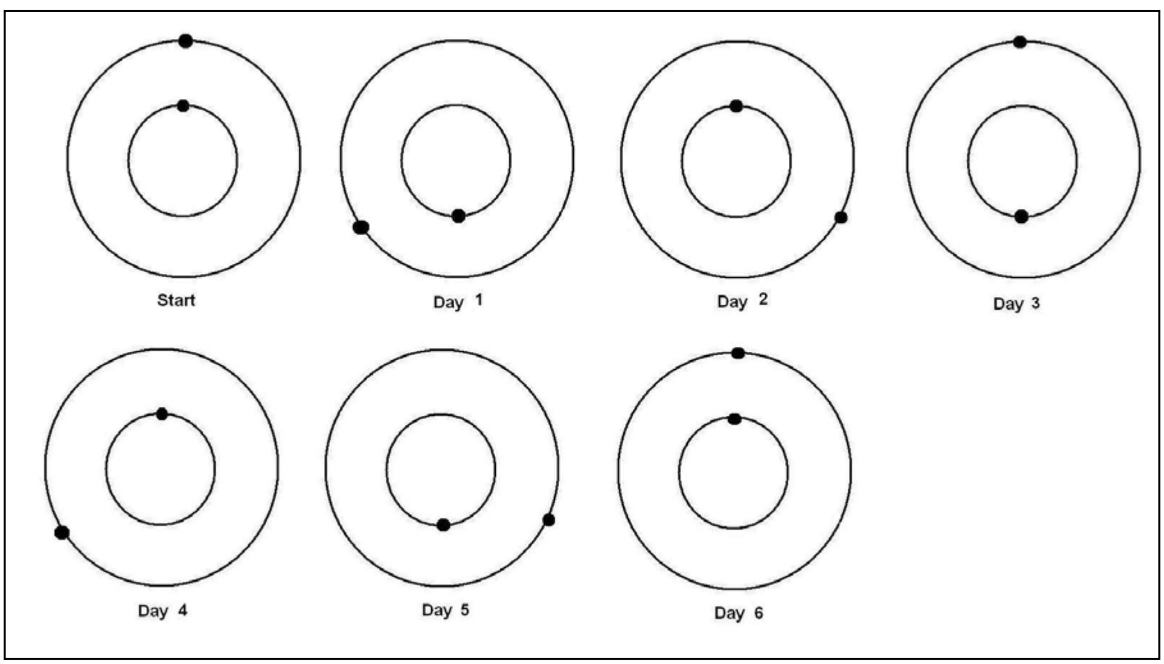
Answer Key

Problem 1 - A) The Least Common Multiple between 2 and 3 is 6, so it will take 6 days for the two moons to return to their original positions. B) The figure below shows the progression in elapsed days, with the moons moving counterclockwise. C) The LCM between the orbit periods tells you how long it will take for the two bodies to return to their same locations when they started.

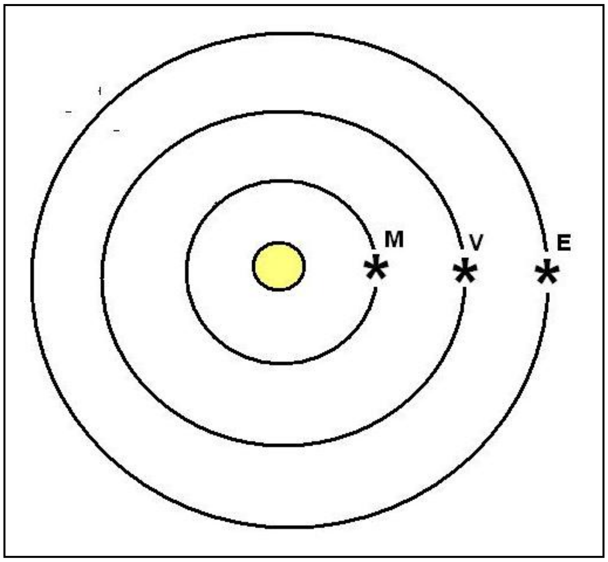
Problem 2 - Two planets have orbit periods of 3 years and 5 years. How long will it take them to return to the same locations that they started at?
Answer; The LCM for 3 and 5 is found by forming the multiples of 3 and 5 and finding the first number they share in common.

For 3: 3, 6, 9, 12**, 15,** 18, 21, 24, 27, 30, 33, 36, ….
For 5: 5, 10, **15,** 20, 25, 30, …

The smallest common multiple is '15', so it will take the two planets 15 years to return to the positions they started with.



Planetary Alignments



One of the most interesting things to see in the night sky is two or more planets coming close together in the sky. Astronomers call this a conjunction. As seen from their orbits, another kind of conjunction is sometimes called an 'alignment' which is shown in the figure to the left and involves Mercury, M, Venus, V, and Earth, E. As viewed from Earth's sky, Venus and Mercury would be very close to the sun, and may even be seen as black disks 'transiting' the disk of the sun at the same time, if this alignment were exact. How often do alignments happen?

Earth takes 365 days to travel one complete orbit, while Mercury takes 88 days and Venus takes 224 days, so the time between alignments will require each planet to make a whole number of orbits around the sun and return to the pattern you see in the figure above. Let's look at a simpler problem. Suppose Mercury takes 1/4 Earth-year and Venus takes 2/3 of an Earth-year to make their complete orbits around the sun. You can find the next line-up from one of these two methods:

Method 1: Work out the three number series like this:

Earth = 0, 1, **2**, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,…
Mercury = 0, 1/4, 2/4, 3/4 ,4/4, 5/4, 6/4, 7/4, **8/4**, 9/4, 10/4, 11/4, 12/4,…
Venus = 0, 2/3, 4/3, **6/3**, 8/3, 10/3, 12/3, 14/3, 16/3, 18/3, 20/3, …

Notice that the first time they all coincide with the same number is at **2 years**. So Mercury has to go around the Sun 8 times, Venus 3 times and Earth 2 times for them to line up again in their orbits.

Method 2: We need to find the Least Common Multiple (LCM) of 1/4, 2/3 and 1. First render the periods in multiples of a common time unit of 1/12, then the sequences are:

Mercury = 0, 3, 6, 9, 12, 15, 18, 21, **24**,
Venus = 0, 8, 16, **24**, 32, 40, …
Earth, 0, 12, **24**, 36, 48, 60, …

The LCM is 24 which can be found from prime factorization:

Mercury: 3 = 3
Venus: 8 = 2 x 2 x 2
Earth: 12 = 2 x 2 x 3

The LCM the product of the highest powers of each prime number or 3 x 2 x 2 x 2 = 24. and so it will take 24/12 = **2 years.**

Problem 1 - Suppose a more accurate estimate of their orbit periods is that Mercury takes 7/30 Earth-years and Venus takes 26/42 Earth-years. After how many Earth-years will the alignment shown in the figure above reoccur?

Problem 1 - Suppose a more accurate estimate of their orbit periods is that Mercury takes 7/30 Earth-years and Venus takes 26/42 Earth-years. After how many Earth-years will the alignment reoccur?

Mercury = 7/30 x 365 = 85 days vs actual 88 days
Venus = 26/42 x 365 = 226 days vs actual 224 days
Earth = 1

The common denominator is 42 x 30 = 1,260 so the series periods are
Mercury = 7 x 42 = 294 so 7/30 = 294/1260
Venus = 26 x 30 = 780 so 26/42 = 780/1260
Earth = 1260 so 1 = 1260/1260

The prime factorizations of these three numbers are

294 = 2 x 2 x 3 x 7 x 7
780 = 2 x 2x 5 x 3 x 13
1260 = 2 x 2 x 3 x 3 x 5 x 7

LCM = 2 x 2 x 3 x 3 x 5 x 7 x 7 x 13 = 114,660

So the time will be 114,660 / 1260 = 91 years! In this time, Mercury will have made exactly 114,660/294 = 390 orbits and Venus will have made 114,660/780 = 147 orbits

Note to Teacher: Why did the example problem give only 2 years while this problem gave 91 years for the 'same' alignment? Because we used a more accurate approximation for the orbit periods of the three planets. Mercury actual period = 88 days but 1/4 Earth-year = 91.25 days compared to 7/30 Earth-year = 85 days. Venus actual period = 224 days but 2/3 Earth-year = 243 days and 26/42 Earth-year = 226 days.

This means that after 2 years and exactly 8 orbits (8 x 91.25 = 730 days), Mercury will be at 8/4 x 365 = 730 days while the actual 88-day orbit will be at 88 x 8 = 704 days or a timing error of 26 days. Mercury still has to travel another 26 days in its orbit to reach the alignment position. For Venus, its predicted orbit period is 2/3 x 365 = 243.3 days so its 3 orbits in the two years would equal 3 x 243.3 days = 730 days, however its actual period is 224 days so in 3 orbits it accumulates 3 x 224 = 672 days and the difference is 730-672 = 58 days so it has to travel another 58 days to reach the alignment. In other words, the actual positions of Mercury and Venus in their orbits is far from the 'straight line' we were hoping to see after exactly 2 years, using the approximate periods of 1/4 and 2/3 earth-years!

With the more accurate period estimate of 7/30 Earth-years (85 days) for Mercury and 26/42 Earth-years (226 days) for Venus, after 91 years, Mercury will have orbited exactly 91 x 365 days/88 days = 377.44 times, and Venus will have orbited 91x365/224 = 148.28 times. This means that Mercury will be 0.44 x 88d = 38.7 days ahead of its predicted alignment location, and Venus will be 0.28 x 224 = 62.7 days behind its expected alignment location. Comparing the two predictions, Prediction 1: Mercury= - 26 days, Venus= - 58 days; Prediction 2: Mercury = +26 days and Venus = - 22 days. Our prediction for Venus has significantly improved while for Mercury our error has remained about the same in absolute magnitude. In the sky, the two planets will appear closer together for Prediction 2 in 1911 years than for Prediction 1 in 2 years. If we want an even 'tighter' alignment, we have to make the fractions for the orbit periods much closer to the actual periods of 88 and 224 days.

Unit Conversions III

1 Astronomical Unit = 1.0 AU = 1.49 x 10^8 kilometers		
1 Parsec = 3.26 Light years = 3 x 10^{18} centimeters = 206,265 AU		
1 Watt = 10^7 ergs/sec		
1 Star = 2 x 10^{33} grams		
1 Yard = 36 inches	1 meter = 39.37 inches	1 mile = 5,280 feet
1 Liter = 1000 cm3	1 inch = 2.54 centimeters	1 kilogram = 2.2 pounds
1 Gallon = 3.78 Liters	1 kilometer = 0.62 miles	

Problem 1 – Convert 11.3 square feet into square centimeters.

Problem 2 – Convert 250 cubic inches into cubic meters.

Problem 3 – Convert 1000 watts/meter^2 into watts/foot^2

Problem 4 – Convert 5 miles into kilometers.

Problem 5 – Convert 1 year into seconds.

Problem 6 – Convert 1 km/sec into parsecs per million years.

Problem 7 - A house is being fitted for solar panels. The roof measures 50 feet x 28 feet. The solar panels cost \$1.00/cm^2 and generate 0.03 watts/cm^2. A) What is the maximum electricity generation for the roof in kilowatts? B) How much would the solar panels cost to install? C) What would be the owners cost for the electricity in dollars per watt?

Problem 8 – A box of cereal measures 5 cm x 20 cm x 40 cm and contains 10,000 Froot Loops. What is the volume of a single Froot Loop in cubic millimeters?

Problem 9 – In city driving, a British 2002 Jaguar is advertised as having a gas mileage of 13.7 liters per 100 km, and a 2002 American Mustang has a mileage of 17 mpg. Which car gets the best gas mileage?

Problem 10 – The Space Shuttle used 800,000 gallons of rocket fuel to travel 400 km into space. If one gallon of rocket fuel has the same energy as 5 gallons of gasoline, what is the equivalent gas mileage of the Space Shuttle in gallons of gasoline per mile?

Problem 11 – The length of an Earth day increases by 0.0015 seconds every century. How long will a day be in 3 billion years from now?

Problem 12 – The density of matter in the Milky Way galaxy is 7.0 x 10^{-24} grams/cm^3. How many stars are in a cube that is 10 light years on a side?

Problem 13 – At a speed of 300,000 km/sec, how far does light travel in miles in 1 year?

Answer Key

Problem 1 – 11.3 x (12 inches/foot)x(12 inches/foot) x (2.54 cm/1 inch)x(2.54 cm/1 inch) = **10,500 cm^2**

Problem 2 – 250 $inch^3$ x $(2.54\ cm/inch)^3$ x $(1\ meter/100\ cm)^3$ = **0.0041 m^3**

Problem 3 – 1000 $watts/meter^2$ x $(1\ meter/39.37\ inches)^2$ x $(12\ inches/foot)^2$ = **93.0 $watts/ft^2$**

Problem 4 – 5 miles x (5280 feet/mile) x (12 inches/foot)x(2.54 cm/inch)x(1 meter/100 cm) x(1 km/1000 meters) **= 8.1 km**

Problem 5 – 1 year x (365 days/year)x(24 hours/day)x(60 minutes/hr)x(60 seconds/minute) = **31,536,000 seconds.**

Problem 6 – 1 km/sec x (100000 cm/km)x(3.1 x 10^7 seconds/year) x (1 parsec/ 3.1 x 10^{18} cm) x (1,000,000 years/1 million years) = **1 parsec/million years**

Problem 7 - A) Area = 50 feet x 28 feet = 1400 ft^2. Convert to cm^2: 1400 x $(12\ inch/foot)^2$ x $(2.54\ cm/1\ inch)^2$ = 1,300,642 cm^2. Maximum power = 1,300,642 cm^2 x 0.03 $watts/cm^2$ = **39.0 kilowatts**. B) 1,300,642 cm^2 x \$1.00 /cm^2 = **\$1.3 million** C) \$1,300,000 / 39,000 watts = **\$33.3 /watt**.

Problem 8 – Volume of box = 5 x 20 x 40 = 4000 cm^3. This contains 10,000 Froot Loops, so each one has a volume of 4,000 cm^3/10,000 loops = 0.4 cm^3/Loop. Converting this into cubic millimeters: 0.4 cm^3 x $(10\ mm/1\ cm)^3$ = **400 mm^3/Loop**.

Problem 9 – Convert both to kilometers per liter. Jaguar = 100 km/13.7 liters = 7.3 km/liter. Mustang = 17.0 x (1 km/0.62 miles) x(1 gallon/3.78 liters) = 7.25 km/liter. **They both get similar gas mileage under city conditions**.

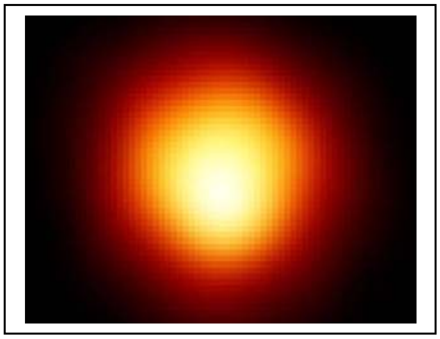
Problem 10 – 400 km x (0.62 miles/km) = 248 miles. Equivalent gallons of gasoline = 800,000 gallons rocket fuel x (5 gallons gasoline/1 gallon rocket fuel) = 4,000,000 gallons gasoline, so the 'mpg' is 248 miles/4000000 = 0.000062 miles/gallon or **16,130 gallons/mile**.

Problem 11 – 0.00015 sec/century x (1 century/100 years) x 3 billion years = 4,500 seconds or 1.25 hours. The new 'day' would be 24h – 1.25 = **22.75 hours long**.

Problem 12 –First convert to grams per cubic parsec: 7.0 x 10^{-24} $grams/cm^3$ x $(3.1 \times 10^{18}\ cm/parsec)^3$ = 2.0 x 10^{32} $grams/pc^3$. Then convert to Stars/pc3: 2.0 x 10^{32} $grams/pc^3$ x (1 Star/2 x 10^{33} grams) = 0.1 $Stars/pc^3$. Then compute the volume of the cube: V = 10x10x10 = 1000 light $years^3$ = 1000 light $years^3$ x (1 parcsec/3.26 light years)3 = 28.9 $Parsecs^3$. Then multiply the density by the volume: 0.1 $Stars/pc^3$ x (28.9 $Parsecs^3$) = **3.0 Stars in a volume that is 10 light years on a side**.

Problem 13 – 300,000 km/sec x (3.1 x 10^7 sec/year) = 9.3 x 10^{12} km. Then 9.3 x 10^{12} km x (0.62 miles/km) = **5.7 trillion miles**.

The relative sizes of the sun and stars



Stars come in many sizes, but their true appearances are impossible to see without special telescopes. The image to the left was taken by the Hubble Space telescope and resolves the red supergiant star Betelgeuse so that its surface can be just barely seen. Follow the number clues below to compare the sizes of some other familiar stars!

Problem 1 - The sun's diameter if 10 times the diameter of Jupiter. If Jupiter is 11 times larger than Earth, how much larger than Earth is the Sun?

Problem 2 - Capella is three times larger than Regulus, and Regulus is twice as large as Sirius. How much larger is Capella than Sirius?

Problem 3 - Vega is 3/2 the size of Sirius, and Sirius is 1/12 the size of Polaris. How much larger is Polaris than Vega?

Problem 4 - Nunki is 1/10 the size of Rigel, and Rigel is 1/5 the size of Deneb. How large is Nunki compared to Deneb?

Problem 5 - Deneb is 1/8 the size of VY Canis Majoris, and VY Canis Majoris is 504 times the size of Regulus. How large is Deneb compared to Regulus?

Problem 6 - Aldebaran is 3 times the size of Capella, and Capella is twice the size of Polaris. How large is Aldebaran compared to Polaris?

Problem 7 - Antares is half the size of Mu Cephi. If Mu Cephi is 28 times as large as Rigel, and Rigel is 50 times as large as Alpha Centauri, how large is Antares compared to Alpha Centauri?

Problem 8 - The Sun is 1/4 the diameter of Regulus. How large is VY Canis Majoris compared to the Sun?

Inquiry: - Can you use the information and answers above to create a scale model drawing of the relative sizes of these stars compared to our Sun.

Answer Key

The relative sizes of some popular stars is given below, with the diameter of the sun = 1 and this corresponds to an actual physical diameter of 1.4 million kilometers.

Betelgeuse	440	Nunki	5	VY CMa	2016	Delta Bootis	11
Regulus	4	Alpha Cen	1	Rigel	50	Schedar	24
Sirius	2	Antares	700	Aldebaran	36	Capella	12
Vega	3	Mu Cephi	1400	Polaris	24	Deneb	252

Problem 1 - Sun/Jupiter = 10, Jupiter/Earth = 11 so Sun/Earth = 10 x 11 = **110 times.**

Problem 2 - Capella/ Regulus = 3.0, Regulus/Sirius = 2.0 so Capella/Sirius = 3 x 2 = **6 times.**

Problem 3 - Vega/Sirius = 3/2 Sirius/Polaris=1/12 so Vega/Polaris = 3/2 x 1/12 = **1/8 times**

Problem 4 - Nunki/Rigel = 1/10 Rigel/Deneb = 1/5 so Nunki/Deneb = 1/10 x 1/5 = **1/50.**

Problem 5 - Deneb/VY = 1/8 and VY/Regulus = 504 so Deneb/Regulus = 1/8 x 504 = **63 times**

Problem 6 - Aldebaran/Capella = 3 Capella/Polaris = 2 so Aldebaran/Polaris = 3 x 2 **= 6 times**.

Problem 7 - Antares/Mu Cep = 1/2 Mu Cep/Rigel = 28 Rigel/Alpha Can = 50, then Antares/Alpha Can = 1/2 x 28 x 50 = **700 times**.

Problem 8 - Regulus/Sun = 4 but VY CMA/Regulus = 504 so VY Canis Majoris/Sun = 504 x 4 = **2016 times the sun's size!**

Inquiry: Students will use a compass and millimeter scale. If the diameter of the Sun is 1 millimeter, the diameter of the largest star VY Canis Majoris will be 2016 millimeters or about 2 meters!

Scientific Notation I

Astronomers rely on scientific notation in order to work with 'big' things in the universe. The rules for using this notation are pretty straight-forward, and are commonly taught in most 7th-grade math classes as part of the National Education Standards for Mathematics.

The following problems involve the conversion of decimal numbers into SN form, and are taken from common astronomical applications and quantities.

1) Length of a year. 31,560,000.0 seconds

2) Speed of light: 299,792.4 kilometers/sec

3) Mass of the sun: 1,989,000,000,000,000,000,000,000,000,000,000 grams

4) Mass of Earth: 5,974,000,000,000,000,000,000,000 kilograms

5) One light-year : 9,460,500,000,000 kilometers

6) Power output of sun : 382,700,000,000,000,000,000,000,000 watts

7) Mass of an electron: 0.00000000000000000000000000000091096 kilograms

8) Energy equivalent of one electron-Volt : 0.00000000000000000016022 joules

9) Ratio of proton to electron mass: 1,836.2

10) Planck's Constant: 0.000000000000000000000000006626068 ergs seconds

11) Radius of hydrogen atom : 0.00000000529177 centimeters

12) Radius of Earth's orbit: 14,959,789,200,000 centimeters

13) Smallest unit of physical distance: 0.0000000000000000000000000000000016 centimeters

14) Diameter of Visible Universe: 26,000,000,000,000,000,000,000,000,000 centimeters

Answer Key:

1) Length of a year. 31,560,000.0 seconds

Answer: 3.156×10^{7} seconds

2) Speed of light: 299,792.4 kilometers/sec

Answer: 2.997924×10^{5} km/sec

3) Mass of the sun: 1,989,000,000,000,000,000,000,000,000,000,000 grams

Answer: 1.989×10^{33} grams

4) Mass of Earth: 5,974,000,000,000,000,000,000,000 kilograms

Answer: 5.974×10^{24} kg

5) One light-year : 9,460,500,000,000 kilometers

Answer: 9.4605×10^{12} km

6) Power output of sun : 382,700,000,000,000,000,000,000,000 watts

Answer: 3.827×10^{26} watts

7) Mass of an electron: 0.00000000000000000000000000000091096 kilograms

Answer: 9.1096×10^{-31} kg

8) Energy equivalent of one electron-Volt : 0.00000000000000000016022 joules

Answer: 1.6022×10^{-19} Joules

9) Ratio of proton to electron mass: 1,836.2

Answer; 1.8362×10^{3}

10) Planck's Constant: 0.000000000000000000000000006626068 ergs seconds

Answer: 6.626068×10^{-27} ergs seconds

11) Radius of hydrogen atom : 0.00000000529177 centimeters

Answer: 5.29177×10^{-9} cm

12) Radius of Earth's orbit: 14,959,789,200,000 centimeters

Answer: $1.49597892 \times 10^{13}$ cm

13) Smallest unit of physical distance: 0.0000000000000000000000000000000016 centimeters

Answer: 1.6×10^{-33} cm

14) Diameter of Visible Universe: 26,000,000,000,000,000,000,000,000,000 centimeters

Answer; 2.6×10^{28} cm

Applications of Scientific Notation

Scientific notation is an important way to represent very big, and very small, numbers. Here is a sample of astronomical problems that will test your skill in using this number representation.

Problem 1: The sun produces 3.9×10^{33} ergs per second of radiant energy. How much energy does it produce in one year (3.1×10^{7} seconds)?

Problem 2: One gram of matter converted into energy yields 3.0×10^{20} ergs of energy. How many tons of matter in the sun is annihilated every second to produce its luminosity of 3.9×10^{33} ergs per second? (One metric ton = 10^{6} grams)

Problem 3: The mass of the sun is 1.98×10^{33} grams. If a single proton has a mass of 1.6×10^{-24} grams, how many protons are in the sun?

Problem 4: The approximate volume of the visible universe (A sphere with a radius of about 14 billion light years) is 1.1×10^{31} cubic light-years. If a light-year equals 9.2×10^{17} centimeters, how many cubic centimeters does the visible universe occupy?

Problem 5: A coronal mass ejection from the sun travels 1.5×10^{13} centimeters in 17 hours. What is its speed in kilometers per second?

Problem 6: The NASA data archive at the Goddard Space Flight Center contains 25 terabytes of data from over 1000 science missions and investigations. (1 terabyte = 10^{15} bytes). How many CD-roms does this equal if the capacity of a CD-rom is about 6×10^{8} bytes? How long would it take, in years, to transfer this data by a dial-up modem operating at 56,000 bits/second? (Note: one byte = 8 bits).

Problem 7: Pluto is located at an average distance of 5.9×10^{14} centimeters from Earth. At the speed of light (2.99×10^{10} cm/sec) how long does it take a light signal (or radio message) to travel to Pluto and return?

Problem 8: The planet HD209458b, now known as Osiris, was discovered by astronomers in 1999 and is at a distance of 150 light-years (1 light-year = 9.2×10^{12} kilometers). If an interstellar probe were sent to investigate this world up close, traveling at a maximum speed of 700 km/sec (about 10 times faster than our fastest spacecraft: Helios-1), how long would it take to reach Osiris?

Answer Key

Problem 1: The sun produces 3.9 x 10^{33} ergs per second of radiant energy. How much energy does it produce in one year (3.1 x 10^{7} seconds)? **Answer:** 3.9 x 10^{33} x 3.1 x 10^{7} = 1.2 x 10^{41} ergs.

Problem 2: One gram of matter converted into energy yields 3.0 x 10^{20} ergs of energy. How many tons of matter in the sun is annihilated every second to produce its luminosity of 3.9 x 10^{33} ergs per second? (One metric ton = 10^{6} grams). **Answer:** 3.9 x 10^{33}/3.0 x 10^{20} = 1.3 x 10^{13} grams per second, or 1.3 x 10^{13}/10^{6} = 1.3 x 10^{5} metric tons of mass.

Problem 3: The mass of the sun is 1.98 x 10^{33} grams. If a single proton has a mass of 1.6 x 10^{-24} grams, how many protons are in the sun? **Answer:** 1.98x10^{33}/1.6 x 10^{-24} = 1.2 x 10^{57} protons.

Problem 4: The approximate volume of the visible universe (A sphere with a radius of about 14 billion light years) is 1.1 x 10^{31} cubic light-years. If a light-year equals 9.2 x 10^{17} centimeters, how many cubic centimeters does the visible universe occupy? **Answer:** 1 cubic light year = (9.2 x 10^{17})^{3} = 7.8 x 10^{53} cubic centimeters, so the universe contains 7.8 x 10^{53} x 1.1 x 10^{31} = 8.6 x 10^{84} cubic centimeters.

Problem 5: A coronal mass ejection from the sun travels 1.5 x 10^{13} centimeters in 17 hours. What is its speed in kilometers per second? **Answer:** 1.5 x 10^{13} / (17 x 3.6 x 10^{3}) = 2.4 x10^{8} cm/sec = 2,400 km/sec.

Problem 6: The NASA data archive at the Goddard Space Flight Center contains 25 terabytes of data from over 1000 science missions and investigations. (1 terabyte = 10^{15} bytes). How many CD-roms does this equal if the capacity of a CD-rom is about 6x10^{8} bytes? How long would it take, in years, to transfer this data by a dial-up modem operating at 56,000 bits/second? (Note: one byte = 8 bits). **Answer:** 2.5 x 10^{16} / 6x10^{8} = 4.2 x 10^{7} Cdroms. It would take 2.5 x 10^{16}/7,000 = 3.6 x 10^{12} seconds or about 1.1 x 10^{5} years.

Problem 7: Pluto is located at an average distance of 5.9 x 10^{14} centimeters from Earth. At the speed of light (2.99 x 10^{10} cm/sec) how long does it take a light signal (or radio message) to travel to Pluto and return? **Answer:** 2 x 5.98 x 10^{14}/2.99 x 10^{10} = 4.0 x 10^{4} seconds or 11 hours.

Problem 8: The planet HD209458b, now known as Osiris, was discovered by astronomers in 1999 and is at a distance of 150 light-years (1 light-year = 9.2 x 10^{12} kilometers). If an interstellar probe were sent to investigate this world up close, traveling at a maximum speed of 700 km/sec (about 10 times faster than our fastest spacecraft: Helios-1), how long would it take to reach Osiris? **Answer:** 150 x 9.2x 10^{12}/700 = 1.9 x 10^{12} seconds or about 64,000 years!