Starship Gaia #12 October 2002

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Measuring Time: the Second | Top

Time is a fundamental physical quantity. It is studied in math, science, and social studies. It is a concept that pervades all real-world activities. Here are ideas and resources to help teachers learn more about time, units of time, and devices for measuring time. Explore these yourself and with students from grades 5 through 12. You will find interesting data for calculator and spreadsheet explorations, examples of applications of math, science, and astronomy, and neat classroom activities and Web demonstrations. [Mention Web supplement. I am not sure how we word these. A.]

The **second** (s) is the SI unit of time. Fasten your seat belt and read the official definition of the second from the National Institute of Standards and Technology site Base unit definitions: Second (http://physics.nist.gov/cuu/Units/second.html).

> The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

Very interesting, but you may prefer Mary Blocksma s description in her book *Reading the Numbers*:

> Since 1967 the second has been based on the absolutely predictable behavior of the cesium atom. In vastly oversimplified terms, the outer electron in the cesium atom flips when exposed to a radio signal of exactly 9,192,631,770 Hz. The quartz oscillator producing this signal is automatically adjusted to keep those electrons jumping, and its frequency divided by 9,192,631,770 is defined as one second.

To learn more, visit the US Naval Observatory's Cesium Atomic Clocks (http://tycho.usno.navy.mil/cesium.html) site. We discovered that cesium atomic clocks measure frequency with an accuracy of 2 to 3 parts in 10^{14}. This corresponds to a time measurement accuracy of 2 *nanoseconds* per day, 0.73 *microseconds* per year, or one second in 1,400,000 years. That's much better than the clock in Paul's classroom.

Precision clocks and stopwatches are handy for measuring time to a tenth or hundredth of a second. Basketball games are timed to a tenth of a second and sometimes won in the last 0.1 s. In the 1996 Olympics, Michael Johnson ran 200 meters in the world-record time of 19.32 s. Three years later he added the 400-meter world record to his collection with a time of 43.18 s.

Motion experiments are terrific tools for learning and teaching math and science. Our favorite toy — er, tool — for measuring motion is the Texas Instruments Calculator-Based Ranger (CBR). Point a CBR at a moving (or unmoving) object to capture its distance, velocity, and acceleration as functions of time. Investigate the CBR at Features - Calculator-Based Ranger (http://education.ti.com/product/tech/cbr/features/features.html) and Calculator-Based Ranger (http://www.vernier.com/calc/cbr.html). We'll move on to motion in a future Starship Gaia column.
[The CBR picture is from vernier.com. See Starship Gaia L&L Vol. 26, No. 3.]

Many years ago, Bob's first computer got things done in *milliseconds*. Today's computers do it in *microseconds* and *nanoseconds*. Coming soon: *picosecond* computers!

- 1 millisecond (ms) = 0.001 s.
- 1 microsecond (µs) = 0.000001 s.
- 1 nanosecond (ns) = 0.000000001 s.
- 1 picosecond (ps) = 0.000000000001 s.

As time marches on and the seconds tick away, we measure time in minutes (min), hours (h), and days (d). These commonly used units are not part of the SI, but are accepted for use with SI units and defined at Definitions of the SI Units: Non_SI units (http://physics.nist.gov/cuu/Units/outside.html), like this:

- 1 minute (min) = 60 s.
- 1 hour (h) = 60 min = 3,600 s.
- 1 day (d) = 24 h = 86,400 s.

The 24-hour day is the **mean solar day**. We'll describe it and another type of day in the section How Long Is a Day?

What Time Is It? | Top

When you ask for the time, we assume you mean the time kept by clocks. A clock may be a bit off, but hopefully not enough to cause you to be late for school, work, or an important date. To be sure, you can set it to **Official U.S. Time** at these Internet sites:

- The Official U.S. Time (http://nist.time.gov/). Click on a time zone to get the time everywhere in that zone and an estimate of the accuracy of the displayed time. Any inaccuracy is due to the time it takes the information to get to your computer over the Internet. Click on Time Exhibits to go to a page of links to timely sites.
- What Time Is It? (http://tycho.usno.navy.mil/cgi-bin/timer.pl) shows the time in all U.S. time zones at the time you load the page. The time is not updated every second as is the time displayed at the NIST site.

Official U.S. time is based on **Coordinated Universal Time** (UTC) kept by the Bureau International des Poids et Mesures in France and time laboratories around the world, including the U.S. Naval Observatory (USNO) and the National Institute of Science and Technology (NIST).

- UTC/TAI Time (http://www.bipm.fr/enus/5_Scientific/c_time/time_server.html)
- Universal Time (http://aa.usno.navy.mil/faq/docs/UT.html)
- World Time Scales (http://physics.nist.gov/GenInt/Time/world.html)

At 12:00:00 UTC, it is high noon at Greenwich, England. The sun is at its highest point in the sky as it transits the Prime Meridian — longitude 0 degrees. In the USA, it is 8:00:00 Atlantic Standard Time, 7:00:00 Eastern Standard Time, 6:00:00 Central Standard Time, 5:00:00 Mountain Standard Time, 4:00:00 Pacific Standard Time, 3:00:00 Alaska Standard Time, 2:00:00 Hawaii-Aleutian Standard Time, and 1:00:00 Samoa Standard Time. U.S. Time Zones (http://aa.usno.navy.mil/faq/docs/us_tzones.html) sports a table showing the number of hours from UTC in US time zones. World travelers can find time zone maps and data at World Time Zone Map (http://aa.usno.navy.mil/faq/docs/world_tzones.html) and Time (http://zebu.uoregon.edu/~js/ast221/lectures/lec04.html).

Time zones are 15 degrees of longitude wide. Actual boundaries are wiggly over land for geographical and political reasons. For example, the Pacific Time Zone includes all of California, Nevada, and Washington, most of Oregon, and part of northern Idaho. At the latitude of San Francisco, it extends from the Nevada-Utah state line (longitude 115° W) to somewhere in the Pacific Ocean.

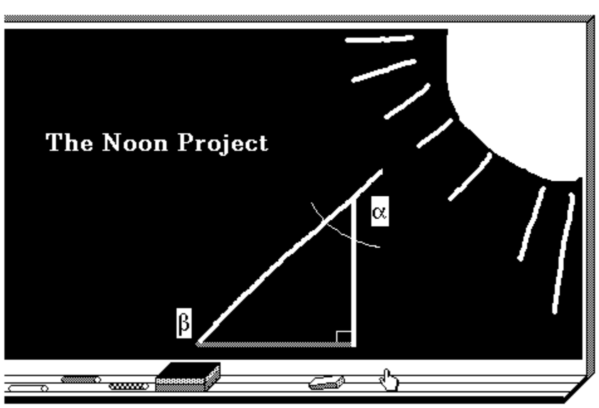
Coordinated Universal Time (UTC) is based on **International Atomic Time** (TAI), calculated by the BIPM from more than 200 atomic clocks located in more than 30 countries. BIPM estimates that TAI does not lose or gain time with an imaginary perfect clock by more than 0.1 microsecond per year.

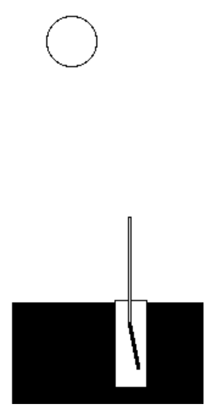
Earth is slowing down — its rotation period is increasing at the rate of 1.4 milliseconds per day per century. To account for this, BIPM periodically adds a *leap second* to the TAI to make sure that the Sun is overhead the meridian of Greenwich within 0.9s of 12:00:00 UTC. Currently, UTC equals TAI minus 32 seconds. To learn more about this boggling byte of befuddlement, go to Leap Seconds (http://tycho.usno.navy.mil/leapsec.html).

As you set your watch to Official U.S. Time, perhaps you're aware that this time is the same everywhere in your time zone. At 12:00:00 standard time, the Sun is at its highest point in the sky — or is it? This happens when the Sun transits the meridian (line of longitude) that you are standing on. Oops! Time zones are approximately 15 degrees of longitude wide — 1667 kilometers at the equator and 1300 kilometers at our latitude (38.5°N). An elementary exercise in critical thinking leads one to realize that the Sun can't be at its highest elevation everywhere in the time zone at the same time.

Apparent Solar Time is time reckoned by the position of the Sun. A sun clock or sundial shows solar time. You can use a sundial to determine your local noon, which is likely to be different than noon on your clock. Oh, you don't have a sundial? Making a sundial is a wonderful project. Learn how at Sundials on the Internet - Five sundial projects for you to make (http://www.sundials.co.uk/projects.htm).
[Sundial is from U of OR site Time (http://zebu.uoregon.edu/~js/ast221/lectures/lec04.html)]

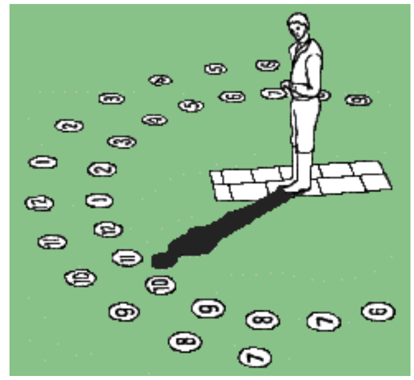
Since it began in 1986, teachers and students from all over the world have participated every year in the Noon Observation Project (http:// w3.ed.uiuc.edu/noon-project/). Using simple measurements and geometry, students collaborate to determine the north-south circumference of the earth, as did Erathosthenes of Alexandria, Egypt in 300 B.C.E. If you participate in this elegant project, you'll begin by determining local noon at your location.
Anita, Add reference to the article that appeared in L&? Also see:
http://www.zip.com.au/~elanora/noon97.html [pictures]
http://205.180.85.40/w/pc.cgi?mid=11094&sid=7271 [spreadsheet by students]
http://w3.ed.uiuc.edu/noon-project/central.html [pictures]
Image below left is from http://w3.ed.uiuc.edu/noon-project/.
Image below right is from http://w3.ed.uiuc.edu/noon-project/project.html.





Our local newspaper lists sunrise and sunset times. We use these times to calculate the standard time of local noon. It's halfway between sunrise and sunset. On November 1, 2002 the times in our neighborhood are:

- Sunrise: 6:38 a.m.
- Sunset: 5:11 p.m.



In 24-hour clock time, 5:11 p.m. is 17:11. Sunset occurs 10 hours, 33 minutes after sunrise. Half of this is 5 hours, 17 minutes (5h 17m). Adding 5h 33m to 6:38 a.m. we get 11:55 a.m. At longitude 122.7° W, we are near the center of our time zone, so our solar noon is close to 12:00:00 Pacific Standard Time. [Human gnomon graphic is from Apparent Solar Time (http://www.weather.gov.hk/gts/time/basicterms-apparentsolartime.htm)

For Sun and Moon data anywhere anytime, go to Complete Sun and Moon Data for One Day (http://aa.usno.navy.mil/data/docs/RS_OneDay.html). Table 1 shows sun transit time (solar noon) for special days of the year at our latitude (38.5° N) and three longitudes in the Pacific Time Zone. Table 2 shows sunrise, sunset, and sun transit times for latitude 38.5°, longitude 120° W on the same special days of the year. Use the sunrise and sunset times to calculate the transit time and compare your result with the transit time shown in the table. A spreadsheet is a great tool for this task.

Table 1. Sun Transit Standard Time (Local Solar Noon) at Latitude 38.5° N

- From **Complete Sun and Moon Data for One Day** (http://aa.usno.navy.mil/data/docs/RS_OneDay.html).

		Longitude		
Date	**Event**	**115° W**	**120° W**	**125° W**
2002-09-23	Autumnal Equinox	11:32	11:53	12:13
2002-12-22	Winter Solstice	11:39	11:59	12:19
2003-01-04	Earth at Perihelion	11:45	12:05	12:25
2003-03-21	Vernal Equinox	11:48	12:08	12:27
2003-06-21	Summer Solstice	11:42	12:02	12:22
2003-07-04	Earth at Aphelion	11:44	12:05	12:24

Table 2. Sunrise and Sunset Standard Times at Latitude 38.5° N, Longitude 120° W

- From **Complete Sun and Moon Data for One Day** (http://aa.usno.navy.mil/data/docs/RS_OneDay.html).

		Pacific Standard Time		
Date	**Event**	**Sunrise**	**Sunset**	**Transit**
2002-09-23	Autumnal Equinox	05:33	17:36	11:32
2002-12-22	Winter Solstice	06:55	16:23	11:39
2003-01-04	Earth at Perihelion	06:58	16:33	11:45
2003-03-21	Vernal Equinox	05:43	17:53	11:48
2003-06-21	Summer Solstice	04:16	19:08	11:42
2003-07-04	Earth at Aphelion	04:21	19:08	11:44

How Long Is a Day? | Top

If you are on a far star looking down on our solar system, you'll see the Earth turn through 360 degrees in one **sidereal day**, which is a little less than 24 hours.

- 1 sidereal day = 23h 56m 4.09s.
- 1 sidereal day = 23.9345 h.

A sidereal day is the length of time between consecutive transits of a point on the celestial sphere (for example, a star) across a given meridian. Suppose you line up a far star in the crosshairs of your telescope at time 0:00:00 on your very accurate timer. In 23 hours, 56 minutes, and 4.09 seconds (1 sidereal day), that same star will again appear centered in the crosshairs. You can verify this by making observations described at Skywatch Project: Length of Sidereal Day (http://www.astro.washington.edu/labs/clearinghouse/labs/Skywatch/LengthOfSiderealDay.htm).

A **solar day** is the time required for Earth to make one rotation *with respect to the Sun*. The duration of a solar day varies slightly as Earth moves around the Sun. The **mean solar day** is 24 hours, the average of a year's worth of solar days. A solar day is a little longer than a sidereal day because Earth is traveling around the Sun. In one mean solar day Earth moves 0.98561° in its orbit, so it must turn 360.98561° to complete one rotation with respect to the Sun. Near perihelion (closest to the Sun) it moves a little farther in its orbit. Near aphelion (farthest from the Sun) it moves a little less. At Timekeeping (http://csep10.phys.utk.edu/astr161/lect/time/timekeeping.html) you can watch an animation that neatly illustrates sidereal and solar days.

The Earth turns 360° in one sidereal day and 360.98561° in one mean solar day. To calculate the length of the mean solar day, multiply the length of the sidereal day by (360.98561°/360°):

- (23.9345 h)(360.98561°/360°) = 24.0000 h. Right on!

Let's turn it around. To calculate the length of the sidereal day, multiply the length of the mean solar day by (360°/360.98561°):

- (24 h)(360°/360.98561°) = 23.9345 h. AOK!

Your Turn. The sidereal rotation period (sidereal day) of Mars is 24.6229 hours and its mean solar day, called a *sol*, is 24.6597 hours.

1. What is Mars's sidereal rotation period in hours, minutes, and seconds. [Answer: 24h 37m 22s]
2. What is the length of Mars's mean solar day in hours, minutes, and seconds? [Answer: 24h 39m 35s]
3. How many degrees does Mars rotate in one sidereal day? [Answer: 360°]
4. How many degrees does Mars rotate in on mean solar day? [Answer: 360.538°]

The Equation of Time | Top

The length of a solar day varies from day to day as Earth goes around the Sun. If you carefully measure the time of local noon everyday for a year, you'll see that the length of a solar day can be less than 24 hours, more than 24 hours, or exactly 24 hours. Add these 365 solar day lengths and divide by 365 to get the length of the *mean solar day*. We hope you get 24 hours. Solar time may be as much as 14 minutes slow in February and 16 minutes fast in November. In February the solar day is longer than 24 hours and in November the solar day is shorter than 24 hours. The solar day is exactly 24 hours long only four days a year.

The **Equation of Time** expresses the difference in the length of a solar day from 24 hours for any day of the year. You can use it to calculate the difference in minutes between solar time measured by your very accurate sundial and standard time measured by your very accurate clock. Figure 1 is a graph of the Equation of Time from Time (http://zebu.uoregon.edu/~js/ast221/lectures/lec04.html). At Equation of Time http://www.ipp.mpg.de/~awc/sundial.html we found equations that approximate the Equation of Time and used them to create an Excel worksheet (Figure 2) and graph (Figure 3) of the Equation of Time.

- E = 9.87 * sin (2B) - 7.53 * cos (B) - 1.5 * sin (B)
- B = 360 * (N - 81) / 364
- N = day number, January 1 = day 1

Why does the length of the solar day vary? One reason is that Earth's orbit is an ellipse, not a circle. It travels at different speeds at different places in its orbit. Another reason is that Earth's equator is inclined 23.45° to the plane of its orbit. So the Sun's apparent path through the sky varies through the year. As its path varies, so does its shadow on your very accurate sundial. For more elucidation, we recommend Internet excursions to these sites:
- Sundials on the Internet - the Equation of Time (http://www.sundials.co.uk/equation.htm).
- ROG: The Equation of Time (http://www.rog.nmm.ac.uk/leaflets/equation/equation.html).

Well, this time we began with the second and worked our way up to a day. Next time we'll talk about months and years. As you may now suspect, there are two or more of each!

Figure 1. Graph of the Equation of Time

- From Time (http://zebu.uoregon.edu/~js/ast221/lectures/lec04.html)

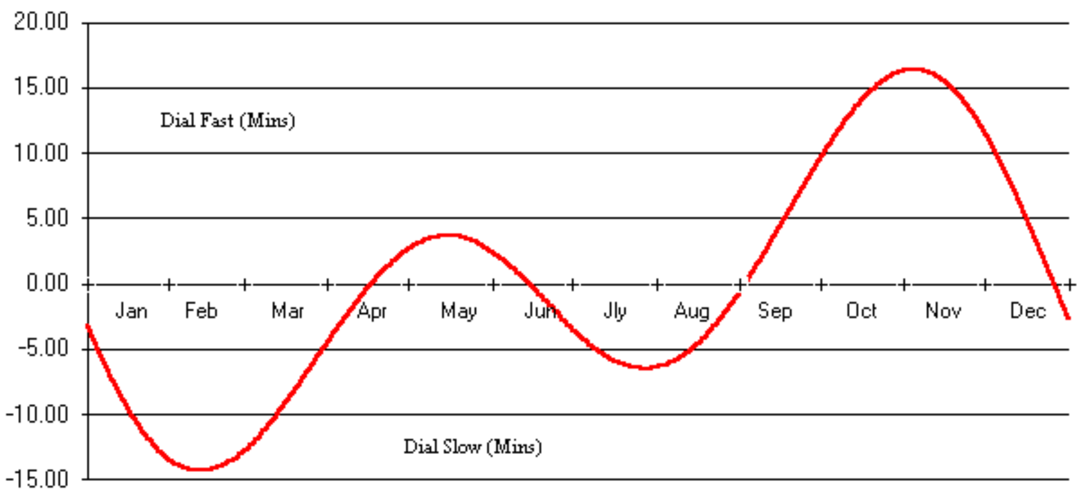
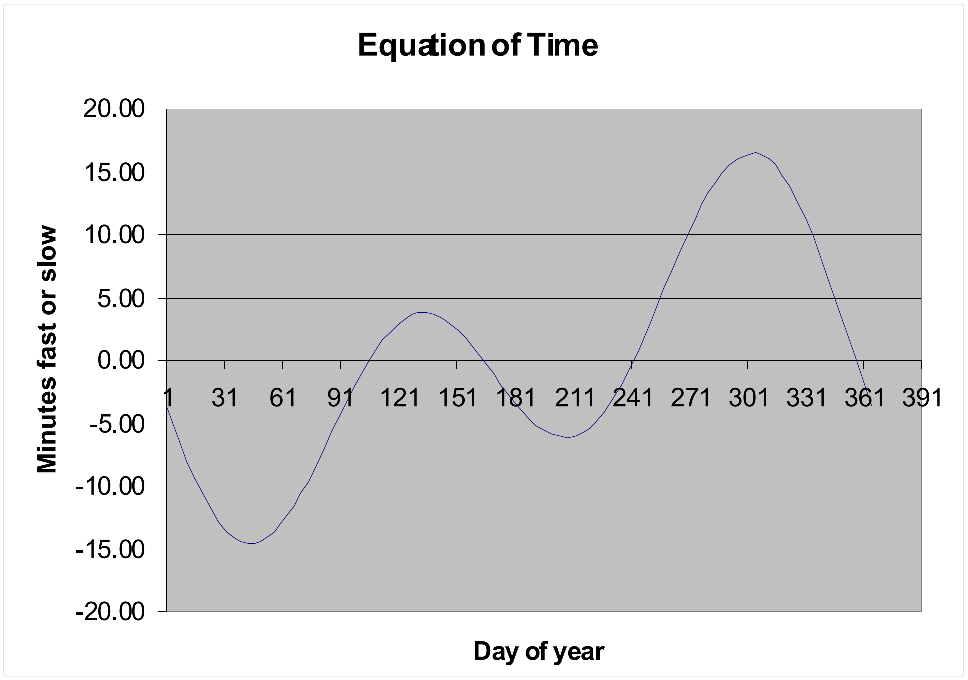


Figure 2. Equation of Time Excel Worksheet

Equation of Time for 2002					
Equation from www.ipp.mpg.de/~awc/sundial.html:					
E = 9.87*sin(2B) - 7.53*cos(B) - 1.5*sin(B)					
B = 360*(N - 81)/364					
N = day number, January 1 = day 1 (day of year, 1 - 366)					

Date			Day of		
Year	Month	Day	year (N)	B	E (min)
2002	1	1	1	-79.1209	-3.61
2002	1	15	15	-65.2747	-9.29
2002	2	1	32	-48.4615	-13.67
2002	2	15	46	-34.6154	-14.57
2002	3	1	60	-20.7692	-13.05
2002	3	15	74	-6.9231	-9.66
2002	4	1	91	9.8901	-4.34
2002	4	15	105	23.7363	-0.22
2002	5	1	121	39.5604	2.93
2002	5	15	135	53.4066	3.75
2002	6	1	152	70.2198	2.33
2002	6	15	166	84.0659	-0.24
2002	7	1	182	99.8901	-3.52
2002	7	15	196	113.7363	-5.62
2002	8	1	213	130.5495	-6.00
2002	8	15	227	144.3956	-4.09
2002	9	1	244	161.2088	0.63
2002	9	15	258	175.0549	5.68
2002	10	1	274	190.8791	11.34
2002	10	15	288	204.7253	14.97
2002	11	1	305	221.5385	16.43
2002	11	15	319	235.3846	14.74
2002	12	1	335	251.2088	9.87
2002	12	15	349	265.0549	3.84
2002	12	31	365	280.8791	-3.61

Figure 3. Equation of Time Excel Graph



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The *International System of Units*, also known as the *Metric System*, is Gaia's world-class, worldwide system of measurement units. Scientists call it *SI*, an abbreviation derived from its French name, *Syst me Internationale d'Unit s*. SI consists of seven *base units* used to measure fundamental physical quantities, and many units derived from the base units.

World headquarters for the SI is at the Bureau International des Poids et Mesures (BIPM) in France (http://www.bipm.fr/enus/3_SI). SI information resides in the USA at the National Institute of Standards and Technology (NIST). Definitions of the SI base units are online at International System of Units from NIST (http://physics.nist.gov/cuu/Units/). Table 1 lists the seven fundamental physical quantities, their SI base units, and symbols for base units.

Table 1 Physical Quantities, SI Base Units, and Base Unit Symbols

- From Current Definitions of the SI Units (http://physics.nist.gov/cuu/Units/current.html).

Physical quantity	SI base unit	Symbol

Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cd
Amount of substance	mole	mol

Browse a physics book or an online physics course and you'll see that much of the course is based on length, mass, time, and physical quantities derived from these three quantities. In previous episodes of Starship Gaia, we've talked about mass, length, and quantities derived from mass and length. Now it's time to talk about time.

Measuring Time: the Second

Definition of the second

- Bureau International des Poids et Mesures in France (http://www.bipm.fr/enus/3_SI/base_units.html).
- NIST Base unit definition: Second (http://physics.nist.gov/cuu/Units/second.html).

Atomic clocks

- The "Atomic Age" of Time Standards (http://physics.nist.gov/GenInt/Time/atomic.html).
- NIST-F1 - Cesium Fountain Atomic Clock (http://www.boulder.nist.gov/timefreq/cesium/fountain.htm).
- US Naval Observatory's Cesium Atomic Clocks (http://tycho.usno.navy.mil/cesium.html).
- Atomic Clocks (http://www.muohio.edu/dragonfly/time/accurate.htmlx).
- Howstuffworks "How Atomic Clocks Work" (http://www.howstuffworks.com/atomic-clock.htm)

Millisecond, Microsecond, Nanosecond, Picosecond

- Powersof10.com (http://www.powersof10.com/powers/time/time.html).
- NASA scientists work to improve optical computing technology (http://science.nasa.gov/headlines/y2000/ast28apr_1m.htm)

Minute, Hour, Day

- Definitions of the SI Units: Non_SI units (http://physics.nist.gov/cuu/Units/outside.html),

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U.S. Time

- NIST: Time and Frequency Division - Division 847 (http://www.boulder.nist.gov/timefreq/index.html).
- The Official U.S. Time (http://nist.time.gov/).
- What Time Is It? (http://tycho.usno.navy.mil/cgi-bin/timer.pl).
- U.S. Time Zones (http://aa.usno.navy.mil/faq/docs/us_tzones.html).
- Free zipcode lookup with area code, county, latitude, longitude, MSA, PM (http://www.zipinfo.com/search/zipcode.htm).
- Foam bath fish time (http://www.savetz.com/fishtime/fishtime.cgi).

Coordinated Universal Time (UTC)

- UTC/TAI Time (http://www.bipm.fr/enus/5_Scientific/c_time/time_server.html).
- Universal Time (http://aa.usno.navy.mil/faq/docs/UT.html).

- World Time Scales (http://physics.nist.gov/GenInt/Time/world.html).
- World Time Zone Map (http://aa.usno.navy.mil/faq/docs/world_tzones.html).
- Time (http://zebu.uoregon.edu/~js/ast221/lectures/lec04.html).
- The World Clock - Time Zones (http://www.timeanddate.com/worldclock/).
- Lesson Plan - Investigation of Time Zones (http://www.spotsylvania.k12.va.us/nspt/teach/ltime01.htm). Grades 6-8.
- humanclock.com - Main menu (http://www.humanclock.com/).

International Atomic Time (TAI)

- UTC/TAI Time (http://www.bipm.fr/enus/5_Scientific/c_time/time_server.html).
- Leap Seconds (http://tycho.usno.navy.mil/leapsec.html).

Solar Time and Sundials

- Mean Solar Time -- from Eric Weisstein's World of Astronomy (http://scienceworld.wolfram.com/astronomy/MeanSolarTime.html).
- Apparent Solar Time (http://www.weather.gov.hk/gts/time/basicterms-apparentsolartime.htm).
- Sundials on the Internet - Five sundial projects for you to make (http://www.sundials.co.uk/projects.htm).
- The Sundial --lesson plan #4 (http://www-istp.gsfc.nasa.gov/stargaze/Lsundial.htm).
- You Can Make a Sundial! (http://www.cyberspace.org/~jh/dial/#horz).
- Science Explorer: Making a Sun Clock--use shadows to tell time! (http://www.exploratorium.edu/science_explorer/sunclock.html).

Local Noon and the Eratosthenes Project

- The Noon Observation Project (http://w3.ed.uiuc.edu/noon-project/).
- Eratosthenes on the Internet (http://www.gsn.org/teach/articles/noon.html). Mentions L&L.
- Complete Sun and Moon Data for One Day (http://aa.usno.navy.mil/data/docs/RS_OneDay.html).

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Sidereal Day

- Sidereal Day — from Eric Weisstein's Worlds of Astronomy (http://scienceworld.wolfram.com/astronomy/SolarDay.html).
- Skywatch Project: Length of Sidereal Day (http://www.astro.washington.edu/labs/clearinghouse/labs/Skywatch/LengthOfSiderealDay.htm).
- Sidereal Time (http://astrosun.tn.cornell.edu/courses/astro201/sidereal.htm).

Solar Day

- Solar Day — from Eric Weisstein's World of Astronomy (http://scienceworld.wolfram.com/astronomy/SolarDay.html).
- Timekeeping (http://csep10.phys.utk.edu/astr161/lect/time/timekeeping.html). Solar and sidereal day animation.

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- Time (http://zebu.uoregon.edu/~js/ast221/lectures/lec04.html).
- Sundials on the Internet — the Equation of Time (http://www.sundials.co.uk/equation.htm).
- ROG: The Equation of Time (http://www.rog.nmm.ac.uk/leaflets/equation/equation.html).
- Equation of Time (http://www.ipp.mpg.de/~awc/sundial.html). Here's the math for Equation of Time calculations, including a set of equations you can use to create an Excel spreadsheet and graph..

- Equation of Time (http://home.netcom.com/~abraxas2/eot.htm). View a table of the Equation of time calculalated for every day of the year.

More Lesson Plans | Top

- Time — Earth Science/Astronomy/Space Science/Physical Science lesson plan (http://school.discovery.com/lessonplans/programs/time/). Grades 6-8.
- Time Lesson Plan (http://www.mcps.k12.md.us/departments/isa/elit/mid/timelp.html). Grade 6.
- The Calendar — lesson plan #10 (http://www-istp.gsfc.nasa.gov/stargaze/Lcalend.htm).
- Eyes on the Sky, Feet on the Ground — Table of Contents (http://hea-www.harvard.edu/ECT/the_book/toc.html). Online book.
- Frick - Lesson Plan (http://sln.fi.edu/time/Frick/Schutte/whatlesson.html).