

Starship Gaia #13

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The Times They Are A-Changin’.

– Bob Dylan

The times, they are a-changin’. Gaia’s day, month, and year, they are a-changin’. Fortunately and thankfully, the second seems to be constant, and is wonderfully well-measured to an abundance of significant digits—it is the foundation of time measurement.

– Laran Stardrake

Subject: Science, math, astronomy,
time

Audience: Teachers

Grade Level: 4–8 (Ages 9 to 13)

Standards: *NETS•S 3*

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, *Système Internationale d’Unités*. Definitions of SI units are online at the National Institute of Standards and Technology site. (*Editor’s Note:* Links to this and other sites mentioned in this article may be found at the end of the article.) The SI unit of time is the **second** (s), defined at Base unit definitions: Second. It is measured with awesome accuracy by atomic clocks like those described at the United States Naval Observatory’s Cesium Atomic Clocks site. The second is a constant foundation of measurement in a sea of time measurements that change oh-so-slowly, such as Gaia’s day and year, and Luna’s orbit around Gaia. More about that later.

A **solar day** is the time for Earth to make one rotation *with respect to Sol* (the Sun). It is the time that elapses between Sol passing through its highest point in the sky two consecutive times—the time that elapses between two consecutive **solar noons**. A solar noon is half way between sunrise and sunset.

The length of a solar day varies as Gaia wends her way around Sol. A solar day can be longer than 24 hours, shorter than 24 hours, or—four days a year—exactly equal to 24 hours. The mean solar day is 24 hours, the average of a year’s worth of solar days. Compared to your very accurate clock, solar time measured by a solar clock (for example, a sundial) may be as much as 14 minutes slow in February and 16 minutes fast in November.

- 1 day = 1 mean solar day = 24 hours = 86,400 seconds.

We reckon larger chunks of time by the week, month, and year. One week has seven days and one month has 28 to 31 days. We use a calendar to keep track of days, months, and years.

In our habitats and classrooms, paper calendars hang on walls and perch on desks, counters, and tables. Electronic calendars reside in computers, in assorted portable gadgets, and on the Internet.

Measuring Time

The **Gregorian calendar** displays 365 days in a **common year** or 366 days in a **leap year**. A leap year is a year that is divisible by 4, except for **centennial years**. Centennial years are multiples of 100 (1900, 2000, 2100, and so on). A centennial year is a leap year only if it is divisible by 400. So 2000 is a leap year, but 1900 and 2100 are not leap years.

- Common years: 1998, 1999, 2001, 2002, and 2003 (non-centennial years, not divisible by 4).
- Common years: 1700, 1800, 1900, 2100, and 2200 (centennial years not divisible by 400).
- Leap years: 1992, 1996, 2004, 2008, and 2012 (non-centennial years divisible by 4).
- Leap years: 1600, 2000, 2400, 2800, and 3200 (centennial years divisible by 400).

Why, oh why is this so complicated? Gaia goes once around Sol in one **tropical year**. A tropical year is the mean interval of time between consecutive **vernal equinoxes**. Alas, alack, and oh heck—a tropical year is not a neat integer number of days, such as 365 or 366. The length of one tropical year is:

- 365.24219 days (mean solar days)
- 365 days, 5 hours, 48 minutes, 45.2 seconds

- 31,556,925.2 seconds.

Is 365 days, 5 hours, 48 minutes, 45.2 seconds equal to 365.24219 days? Well, 365 is equal to 365, so we used a calculator to determine whether 5 h, 48 m, 45.2 s is equal to 0.24219 days (d). In generic form with appropriate units, here is our calculation:

1. $(5 \text{ h})(3600 \text{ s/h}) + (48 \text{ m})(60 \text{ s/m}) + 45.2 \text{ s} = 20925.2 \text{ s}$.
2. $(20925.2 \text{ s}) / (86,400 \text{ s/d}) = 0.24219 \text{ d}$. Looking good!

Use your calculator to verify our calculation. You can also use Excel's handy **TIME function**. First format an Excel worksheet cell as **Number** with **5 decimal places** and then enter the TIME function into the cell as

- = TIME(hours, minutes, seconds).

Table 1 shows examples of the Excel TIME function.

Your Turn. Use your favorite number-crunching tool to convert a measure of a tropical year to another measure of a tropical year.

1. Convert 365.24219 days to seconds. 1 day = 86,400 seconds. [Answer: 31,556,925.2 s]
2. Convert 365.24219 days to days, hours, minutes, and seconds. [Answer: 365d 5h 48m 45.2s]

3. Convert 31,556,925.2 seconds to decimal days. [Answer: 365.24219 d]
4. Convert 31,556,925.2 seconds to days, hours, minutes, and seconds. [Answer: 365d 5h 48m 45.2s]
5. Convert 365d 5h 48m 45.2s to seconds. [Answer: 31,556,925.2 s]

About Calendars

Long ago, the Egyptian astronomers knew that the length of a year was in the neighborhood of 365 days. They observed, measured, calculated, and pinned down the year to about 365.25 days.

The Greek astronomer Hipparchus did even better—he calculated 365.242 days, very close to today's value of 365.24219. Imagine doing this by hand without a calculator or computer. What media and writing instrument did he use? Perhaps he wrote his equations with a bone or metal stylus on a **diptych** (waxed tablet).

In 48 B.C.E., Julius Caesar learned from the Alexandrian astronomer Sosigenes that the Roman calendar was totally out of whack and woefully inadequate for the ambitions of Rome's expanding empire. In 46 B.C.E. Julius introduced a new calendar later called the **Julian calendar**. It has the same months as today's calendars. He added a **leap day** at the end of February on years divisible by 4. The Julian

Table 1 Use Excel's TIME Function to Calculate a Decimal Fraction of a Day

- The cell containing the TIME function is formatted as **Number** with **5 decimal places**.

Excel TIME Function	Value	Comments
= TIME(0, 0, 0)	0.00000	Midnight
= TIME(6, 30, 0)	0.27083	6:30 A.M.
= TIME(12, 0, 37)	0.50043	37 seconds after noon
= TIME(23, 59, 59)	0.99999	1 second before midnight
= TIME(5, 48, 45.2)	0.24219	5 hours, 48 minutes, 45.2 seconds

Table 2 Common and Leap Years in 400 years of the Gregorian Calendar

Type of year	Number of years	Days per year	Total number of days	Average days per year
Non-centurial common	300	365	109,500	
Non-centurial leap	96	366	35,136	
Centurial common	3	365	1,095	
Centurial leap	1	366	366	
Totals	400		146,097	365.2425

Calendar has a period of four years with three years having 365 days and one year having 366 days. Let's calculate the average number of days (d) in a Julian year (y).

- Average Julian year = $[(3 y)(365 d/y) + (1 y)(366 d/y)] / 4 = 365.25 d$.

The average Julian year is slightly longer than the tropical year. The difference is

- $365.25 d - 365.24219 d = 0.00781 d$. About 11 minutes.

Time passed and the 0.00781-day per year difference accumulated. By the 1500s it had become almost 13 days. This difference was bothersome to the leaders of the Roman Catholic Church because it affected the dates of religious holidays. In 1582, Pope Gregory XIII established the Gregorian calendar that we use today. It has a cycle of 400 years with 146,097 total days, and an average of 365.2425 days per year, as shown in Table 2.

The average Gregorian year is much closer to the tropical year than is the Julian year. The difference is

- $365.2425 d - 365.24219 d = 0.00031 d$. About 0.45 minute.

The story of the Julian and Gregorian calendars is much more complicated than described in our simplified sketch. For much more information, visit the Internet sites listed in the Resources section.

Much of the above is neatly summarized in a great cartoon by Jay Ryan. We found it amidst a cornu-

copia of astronomy cartoons at The SkyWise Archive.

The Julian Date

Suppose someone was born on January 1, 1972. How many days has he or she been alive on January 1, 2003? You can verify that in those 31 years there are 23 common years and 8 leap years. That person has enjoyed a number of days equal to

- $23(365 \text{ days}) + 8(366 \text{ days}) = 11,323 \text{ days}$.

Suppose someone was born March 21, 1927. How many days will she or he have lived on September 21, 2002? Or July 4, 2003? Or – well, we'll leave these calculations for you to do. Fortunately, you can go to the Internet and use a **Julian Date Calculator** to quickly do this task. A Julian Date, also called a **Julian Number**, is the number of days and fractions of days since noon Universal Time (UT) January 1, 4713 B.C.E. on the Julian Calendar.

We used the Julian Date Converter to calculate the number of days from noon January 1, 1972 to noon January 1, 2003.

- Julian date of January 1, 2003 = 2452641.
- Julian date of January 1, 1972 = 2441318.
- Number of days = $2452641 - 2441318 = 11323$.

You can use Excel's **DATE function** to calculate the Julian number of days from January 1, 1900 to any date you enter up to December 31, 9999. First format an Excel worksheet cell as **Number with 0 decimal places** and then enter the DATE function into the cell as

- = DATE(year, month, day)

Table 3 shows examples of the Excel DATE function.

The Times, They Are A-Changin'

Nine hundred million years ago, Gaia spun faster and the solar day was shorter—about 18 hours (64,800 seconds) long. The length of the year was 481 of those 18-hour days. Luna was closer to Gaia than now. Gravitational interactions between the two caused Gai's rotation speed to slow down and Luna to move farther from Gaia. In approximately 1820, the length of the mean solar day was

Table 3 Use Excel's DATE Function to Calculate the Number of Days

- The cell containing the DATE function is formatted as Number with 0 decimal places.

Excel DATE Function	Day	Comments
= DATE(1900, 1, 1)	1	January 1, 1900 is day 1.
= DATE(1900, 1, 2)	2	January 2, 1900 is day 2.
= DATE(1900, 12, 31)	366	1900 is a Julian leap year!
= DATE(1972, 1, 1)	26299	January 1, 1972
= DATE(2003, 1, 1)	37623	January 1, 2003
= DATE(2003, 1, 1) – DATE(1972, 1, 1)	11323	Number of days between dates

exactly 86,400 seconds. Since then it has been increasing at the rate of roughly 1.4 milliseconds per century and Luna is moving out at about 3.8 centimeters per year.

It's been 1.83 centuries since 1820, so we calculated the increase in the length of the mean solar day as $(1.4 \text{ ms/century})(1.83 \text{ century}) \approx 2.6 \text{ ms}$. Thus we get 86,400.0026 seconds for the current length of the mean solar day, and it's a-changin'. Several Internet sources say that the mean solar day is now 86,400.002 seconds.

Resources

National Institute of Standards and Technology: <http://physics.nist.gov/cuu/Units/>

US Naval Observatory's Cesium Atomic Clocks site: <http://tycho.usno.navy.mil/cesium.html>

Eric Weisstein's World of Astronomy: <http://scienceworld.wolfram.com/astronomy>

NOAA Improved Sunrise, Sunset, and Solar Noon Calculation: <http://www.srrb.noaa.gov/highlights/sunrise/sunrise.html>

From Stargazers to Starships: <http://www-istp.gsfc.nasa.gov/stargaze/>

Britannica.com Clockworks: Measuring Time: http://www.britannica.com/clockworks/t_article2.html

Hipparchus: <http://www-gap.dcs.st-and.ac.uk/~history/Mathematicians/Hipparchus.html>

The Julian and Gregorian Calendars: http://www.hermetic.ch/cal_stud/cal_art.htm

Information on Leap Years from the US Naval

Observatory: http://aa.usno.navy.mil/faq/docs/leap_years.html

The SkyWiseArchive: <http://www.mangobay.cc/users/moonfinder/subject.htm> Click on Calendar and Timekeeping and then click on Gregorian Calendar.

Julian Date Converter: <http://aa.usno.navy.mil/data/docs/JulianDate.html>

Ask the Space Scientist about: Earth – Rotation: <http://image.gsfc.nasa.gov/poetry/ask/arot.html>

The Nine Planets – The Moon: <http://seds.lpl.arizona.edu/nineplanets/nineplanets/luna.html>

Curious About Astronomy: Is the Moon moving away from the Earth? <http://curious.astro.cornell.edu/question.php?number=124>

Bob Albrecht (*StarshipGaia@aol.com*) is a writer and developer of science, math and technology curricula. *George Firedrake* is his alter ego and takes the form of a dragon. *Laran Stardrake*, whose quotes sometimes lead off the column, is another of Bob's "accomplices." She's half dragon and half human. As Laran is fond of saying, "Reality expands to fill the available fantasies." The *DragonFun* image is from an original painting by Marcy Kier-Hawthorne.

Paul Davis (*nsn@hdo.net*) recently retired from teaching high school math and now lives in Alturas, California. He was a happy, normal teacher until he met Bob Albrecht and George Firedrake in 1992 and became another one of their accomplices. Since then Paul has been intertwining math, science and technology with the help of Bob and George.
