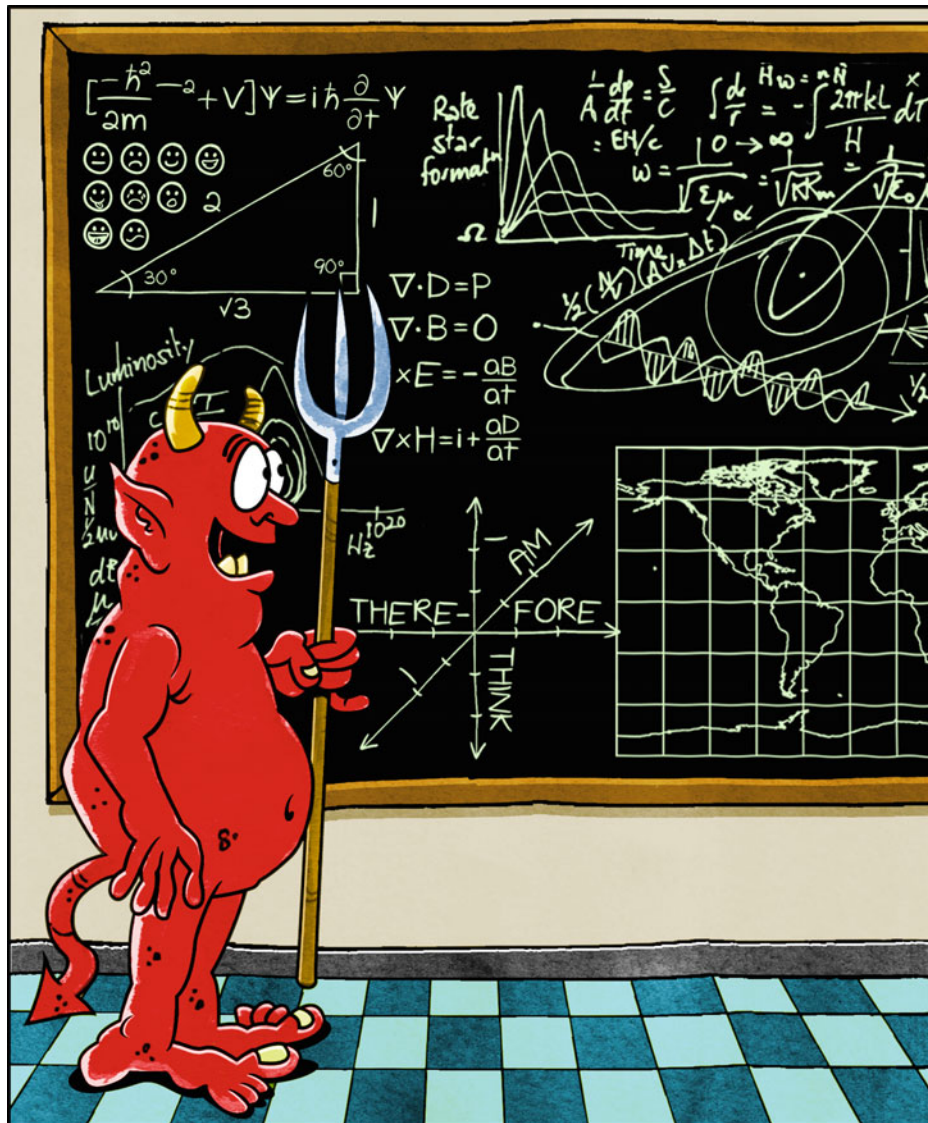




THE DEVIL INVENTS MATHEMATICS

If I were again beginning my studies, I would follow the advice of Plato and start with mathematics.
Galileo Galilei

In this chapter we review the scientific terminology and the mathematics used in this book. Climate change is an incredibly complex topic involving many if not all different fields of science. This book discusses many aspects of science and their relation to climate change may not be immediately obvious. Many topics will creep back in later in an unexpected way. Science involves factual knowledge; concrete facts are often expressed and manipulated as numbers; the language of science is mathematics.

Although this book should be of interest to just about anyone with an interest in science, and the history of science, it is my assumption is that the reader will be an American. By “American” I mean a resident of the United States of America. There are lots of other Americans both to the north and south of the borders of the United States and some of them don’t appreciate our usurpation of the term. As you will see, Americans are the only people on Earth stuck with using an archaic “English” system of weights and measures. We call it the ‘English’ or (rarely) ‘American’ system. It was also used throughout the British Commonwealth (formerly the British Empire) until the latter part of the 20th century; they called it the ‘Imperial’ system.

All other people—even the English—use the much simpler ‘metric system.’ As a result, many Americans treat science as some sort of bizarre field of inquiry based on a foreign language. The language of science is divorced from everyday use in the United States. That undoubtedly has a lot to do with the fact that U.S. students’ science scores rank at or near the bottom of those of the industrialized countries. It also helps explain why more than half the members of the US Congress prefers to accept religious dogma over scientific facts when making decisions about climate change.

You were probably taught much of what is in this chapter in grade school or high school, but you may not have clearly understood some of it, and chances are that you have forgotten a lot of it. I suggest that you at least skim over it if you don’t want to read it all now, and you can always come

back to these topics later. However, I should point out that this chapter does include a lot of background information that you likely did not learn in school. It is especially useful for stimulating conversation at cocktail parties or getting to know people at the local bar.

A note about dates cited in this book: Here I use CE = Common Era (or Christian Era) rather than AD (Anno Domini) with its religious connotation and BCE = Before Common Era = BC of Christians.

Aristotle (384–322 BCE) defined mathematics as “the science of quantity,” but it is much more than that; it is an adventure for the curious mind. It requires the rigorous application of logic to reach conclusions. It does not allow for “miracles,” they are the property of religions.

In his 1992 book *Planet Earth* Cesare Emiliani noted that Americans have a singular aversion to mathematics. He suggested that this might be because many Americans consider themselves to be very religious Christians. There is only the simplest of arithmetic in the Bible and not much of even that. Since there is no math in the Bible, Cesare conjectured that God did not invent it. If God did not invent it, he concluded, it must be the work of the Devil!

2.1 Numbers and Symbols

As the universal language of science: mathematics involves the rigorous use of numerals, symbols, and concepts based on the application of logic to understand phenomena and make predictions. The simplest forms of math are called “arithmetic” including addition, subtraction, multiplication, and division. From these simple calculations developed the more complex equations we refer to as “algebra.” Then followed the development of the more sophisticated technique of exploring changes in rates, termed “calculus.”

At the beginning of the 20th century it was thought that the Greeks had “invented” mathematics in about 700 BCE.

by 1, 2, and 5, but the base 60 of the Babylonian system is divisible by 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, and 30 avoiding many of the fractions that can make calculations of division troublesome. It is also easier to do many other mathematical operations in the “Babylonian” sexagesimal system. They were able to determine areas of land, calculate compound interest, and take square roots of numbers. Today we use the Babylonian system for time, geometry, and geography. A cuneiform tablet (YBC 7289) in the collections of Yale University, dated to between 1,900 and 1,700 BCE, gives the square root of 2 (in modern terminology) as 1.41421296 (Fig. 2.2); the modern value is 1.41421356.... Not bad.

Why would the Babylonians (or anyone else for that matter) want to know the square root of 2 or any other complicated number for that matter? It was important to them in measuring areas of land and determining the lengths of the sides of triangles in constructing buildings. Today not only land surveyors, but, engineers, architects, construction workers, carpenters, artists, and designers use square roots in any kind of work that involves triangles. In finance, the square root of time is used in determining the volatility of market prices. Your Hedge Fund manager should know all about this.

Figure 2.1 compares numerals used by different cultures. The Egyptian hieroglyphic numerals, similar to Hebrew numerals (not shown), are written with the smallest unit on the left and the largest on the right—opposite to the convention used in the other numeral systems shown. Note that the Egyptians, Greeks, and Romans and the Europeans during the Dark Ages did not have a numeral symbol for zero. Instead of a symbol, they simply inserted an empty space in the list of numerals making up the number. This could lead to problems if you didn’t notice the space. The numeral zero was introduced to Europe in 1202 in the book *Liber Abaci* by Leonardo Bonacci, also known as Leonardo of Pisa or as Fibonacci (from fils Bonacci, meaning son of Bonacci). He had been born in North Africa and his numerals, derived from those used in India and Persia became known as “Arabic Numerals.” The European versions of these Arabic numerals that are in use across the world today are a little more than 200 years old. Ironically, the numerals commonly used in most of the Arab world today are quite different from these “Arabic” symbols.

Although the Babylonians had a symbol for zero, they recognized that it was a very strange number. Add or subtract zero from another number and the answer is the other number. Multiply zero by a number and the answer is zero. Division by zero was long a mystery. Any number divided by zero has the same answer: infinity (beyond the finite numbers). It took centuries to figure this mystery out, eventually resulting in a special symbol for infinity: ∞ .

One evening I was seated next to Buckminster Fuller, the famous architect, inventor of the geodesic dome, and all-round thinker/philosopher, at a dinner party. I was able to

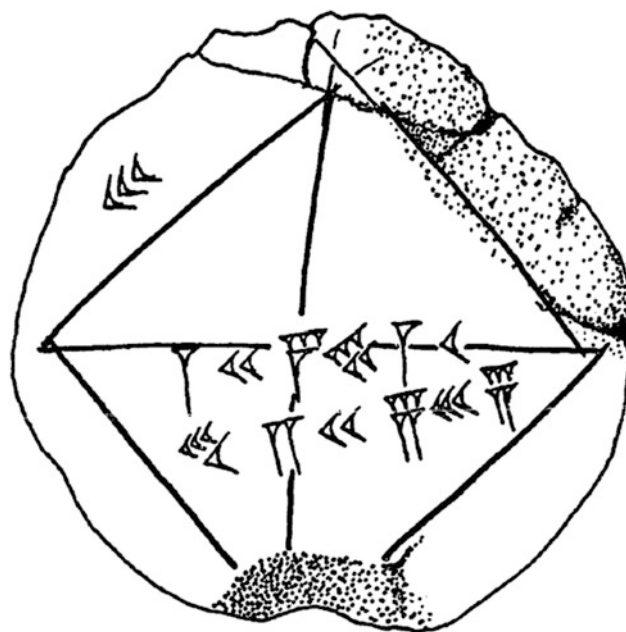


Fig. 2.2 Babylonian Tablet YBC 7289 showing the number for the square root of 2 ($\sqrt{2}$) in the context of a square with two diagonals connecting opposite corners, forming two ‘wedges’. More than a 1000 years later this would be transformed into a simple *triangle* as Pythagoras theorem that the sum of the squares of the two sides adjacent to the right angle is equal to the square of the hypotenuse. (Discussed in detail in the section of the next chapter: Trigonometry.)

ask him questions that had troubled me since I was a child. “Why is a right angle 90° , not 100° ?” His answer was my introduction to Babylonian mathematics: “Because it’s a quarter of the way around a circle. The circle has 360° because that was an old approximation for the number of days in a year. Incidentally, the Babylonians liked to use 60 as the base for a numbering system, so that’s why there are 60 s in a minute, 60 min in a degree (or hour) etc. The ‘second’ is quite ancient, based on the human pulse rate (normal = 60 per minute). We carry a clock around internally. So the Babylonians favored multiples of 60 for different things.” My next question to Bucky was even more profound. “Why do we build rooms as rectangles, with square corners?” Answer: “I think it’s a carryover from making the angle between the wall and the floor 90° . People found out early on that if that angle is not 90° the wall falls over.” My question and his answer were not really as stupid as they sound. There are some ancient round buildings shaped like a dome that avoided these rules, but Bucky Fuller was the first person to really throw these ancient ideas out the window and start out with new geometric rules for architecture. In his structures, such as the geodesic domes, the walls are not 90° from the horizontal, and they don’t fall over. Bucky coined the term ‘spaceship Earth’ and he thought we ought to accept responsibility for keeping it in working order. If you want a mind-bending experience read one of his books entitled ‘*Synergetics*.’

2.2 Arithmetic, Algebra, and Calculus

The derivations and Oxford English Dictionary (OED) definitions of these terms are as follows:

Arithmetic (from Latin *arithmetica*): the science of numbers; the art of computation by figures. Americans learn this in grade school and most find it fun.

Algebra: [from the Arabic *al jabr*, meaning “reunion of broken parts”. Introduced ca. 825 by Baghdad mathematician Abu Ja’far Muhammad ibn Musa al-Khwarizmi in the title of his book on equations *Al Kitab Fi Hisab Al Jabr Wa Al Muqabala* الكتاب المختصر في حساب الجبر و المقابلة, (The Compendious Book on Calculation by Completion and Balancing—The Science of Transposition and Cancellation).] It was al-Khwarizmi who introduced “Arabic” numerals to the West. It was originally defined as the branch of mathematics in which letters are used to represent numbers in formulae and equations, but later defined as that field of mathematics in which symbols are used to represent quantities, relations, operations, and other concepts, and operations may be applied only a finite number of times. Taught in

the United States in High School, algebra often leaves students apprehensive about mathematics.

Calculus: (from Latin *calculus* meaning “reckoning or account.”) The methods were developed independently late in the 17th century by Gottfried Wilhelm Leibniz (1646–1716) and Isaac Newton (1642–1727) for very different purposes; Leibniz used calculus as a mathematical exercise used among other things to determine the ever-changing curvatures used in Baroque architecture; Newton used it to investigate physics. The OED defines it as a system or method of calculation, ‘a certain way of performing mathematical investigations and resolutions;’ a branch of mathematics involving or leading to calculations, as the differential or integral calculus, etc. The differential calculus is often spoken of as ‘the calculus.’

Calculus is taught in the United States in a few High Schools but mostly to College and University students planning careers in Science or Engineering. Mention of the word strikes terror into the hearts of most Americans. Never mention this word at a cocktail party unless you want to drink alone. On the other hand, Russians find it fun (Fig. 2.3).

Fig. 2.3 Francesco Borromini’s baroque church, the Oratorio dei Filippini, built between 1637 and 1650 in Rome. The façade is intended to suggest a human with outstretched welcoming arms. An early example of baroque architecture with the kinds of curves that would later be refined and elaborated by architects using Leibniz’s calculus

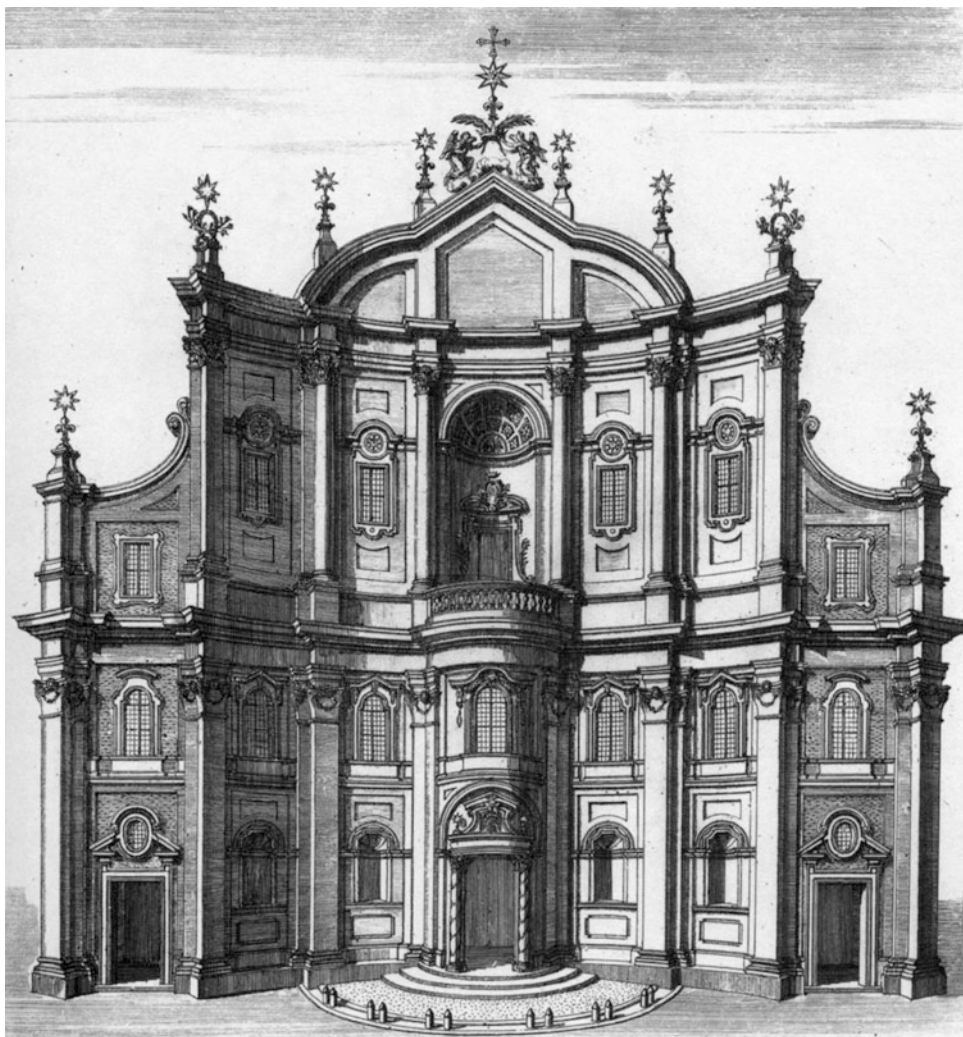




Fig. 2.4 Interior of the pilgrimage church Vierzehnheiligen, built by architect Balthasar Neumann between 1743 and 1772. Calculus was used to compute the elaborate curves

You can immediately recognize calculus by the symbols it uses, originally suggested by Leibnitz:

In differential calculus:

$$\frac{dy}{dt} = z$$

Meaning the change in y (dy) over the change in time (dt) is z

In integral calculus:

$$\int_0^{\infty} z$$

Meaning that z is the total amount of a continuous quantity taken between the limits x (0) and y (∞). Leibniz's original differential and integral signs, M and $\int$ are a reflection of the beautiful curvatures of baroque design. One of the Baroque churches that required calculus for its design is the pilgrimage church of Vierzehnheiligen, near Bamberg, Germany (Fig. 2.4).

Leibniz remarked that "Music is a hidden arithmetic exercise of the soul, which does not know that it is

counting." Much of the music of baroque composer Johann Sebastian Bach (1685–1750) is like the mathematical progressions of calculus expressed in sound.

2.3 Orders of Magnitude and Exponents

The numbers used in discussions about the Earth can get very large. So, rather than writing them out completely, scientists often denote them as small numbers multiplied by some power of ten. The power of ten is the number of zeros that come after the first numeral(s) in the number or before the decimal point in the number. For example, 10 can be written 1×10^1 , but that actually takes up more space. This system becomes more useful when the number is very large. Written out, one trillion is 1,000,000,000,000. In scientific notation it is 1×10^{12} (with 12 designating the number of zeros that come after the 1). Using exponents saves space and means the reader does not need to count the number of digits.

Incidentally, humans inherently have a hard time with numbers as large as ten. A good friend, Lev Ropes, who

specializes in designing presentations at scientific meetings, explained to me that humans generally have difficulty with numbers past seven. We can remember seven items easily enough, but things get difficult after that. This is probably why there are 7 days in a week. Seven is also a special number in Judeo-Christian religion, with seven candles on the Menorah, seven deadly sins, seven seals and seven trumpets in the book of Revelation, and several other sevens. You may have also noticed that after the first 8 months of the year, January through August, the rest are named for numbers, albeit starting with seven (September). I was surprised to learn that we have a hard time keeping more than seven colors straight. A person looking at a diagram with ten colors will spend most of their time trying to figure out how many colors there are rather than understanding what the diagram is meant to show.

Scientists, particularly geologists and astronomers, deal with large numbers. Geologists' numbers refer to time; astronomers' numbers refer to distances—which, incidentally, are measured by the length of time light takes to cover a distance (light-years). Chemists and physicists deal with both very large and very small numbers.

Powers of ten can be expressed with words. 1×10^1 is ten or a “deca” (as in decade), 1×10^2 is a hundred or “hecto,” 1×10^3 is a thousand or “kilo.” Names for larger powers represent increases of three decimal places. Thus, 1×10^6 is a million or “mega,” 1×10^9 is a billion or “giga,” 1×10^{12} is a trillion or “tera,” 1×10^{15} is a quadrillion or “peta,” 1×10^{18} is a quintillion or “exa,” 1×10^{21} is a sextillion or “zeta,” 1×10^{24} is a septillion or “yotta.” The latter terms have yet to find much use. If you know a bit of Latin and understand the prefixes used you will realize that these ‘illion’ terms used in the United States make no sense. A quintillion simply has three more zeros than a quadrillion. The “zillion” you sometimes hear has no specific meaning. It is simply slang used to mean a large number. Table 2.1 shows the terms in common use.

On the other hand, numbers that are used to describe atoms can get very small. So, going in the other direction the base 10 scale, 10^0 is 1, 10^{-3} is a “milli,” 10^{-6} is a “micro,” 10^{-9} is a “nano,” and 10^{-12} is a “pico.” One thousandth of a meter is a millimeter (mm). The limit of visual acuity of the unaided human eye is about 0.1 mm. One millionth of a

meter is a micrometer or micron (μ). The limit of resolution of a light microscope is about $1/4 \mu\text{m}$. One billionth of a meter is a nanometer (nm). The wavelengths of visible light are between 400 and 700 nm. (The wavelength (λ) is the distance from crest to crest or trough to trough of a series of waves). An Ångström is 0.1 nm (10^{-10} m). Atoms are a few Ångströms in diameter.

Because we have a hard time visualizing large numbers, they may tend to blur, and a trillion may not sound much different from a billion. Politicians seem to suffer the most from this inability to distinguish between large numbers. When I was living in Washington, D.C., in the early 1980s, many politicians were fond of using the expression: “A billion here, a billion there, before you know it, it begins to add up to real money.” Members of Congress seem to have mastered the transition from a billion to a trillion with no effort at all. Somehow the US national debt (as of February 3, 2015) of \$18,091,422,494,095.17 seems less formidable when rounded off and written as $\$18.091 \times 10^{12}$, but it is just as large. The daily increase in debt of \$2,370,000,000 looks trivial when written as $\$2.4 \times 10^9$.

The three most commonly used measurement terms in climate studies are “hectopascals” (often incorrectly spelled “hectapascals”) to describe atmospheric pressure (replacing the older term millibars); gigaton, equal to 1 billion (10^9) metric tons, useful in discussing the amounts of material used by humans, and petawatt, equal to 1 quadrillion (10^{15}) watts, used in discussions of Earth’s energy budget.

Countries other than the United States have different terms for numbers larger than a million. In Great Britain, a billion used to be the same as a U.S. trillion, but the British meaning has recently been changed to conform to the US meaning. Outside the United States the prefix “bi” means twice as many zeros as in a million; “tri” means three times as many zeros, and so on. A European trillion is an American quintillion. Sooner or later US politicians will discover they can make budget deficits sound much smaller by using the European system, just as UK politicians have realized they can make investment in public services sound bigger by using the American system!

Curiously, the otherwise logical scientific community uses the US system of nomenclature for large numbers.

Table 2.1 Commonly expressions for orders of magnitude used in the Earth sciences

Number	Scientific notation	Name	Prefix	Number	Scientific notation	Name	Prefix
10	1×10^1 or 1×10^1	Ten	deca-	1	1×10^0 or 1×10^0	One	–
100	1×10^2 or 1×10^2	Hundred	hecto-	0.1	1×10^{-1} or 1×10^{-1}	Tenth	–
1,000	1×10^3 or 1×10^3	Thousand	kilo-	0.01	1×10^{-2} or 1×10^{-2}	Hundredth	–
1,000,000	1×10^6 or 1×10^6	Million	mega-	0.001	1×10^{-3} or 1×10^{-3}	Thousandth	milli-
1,000,000,000	1×10^9 or 1×10^9	Billion	giga-	0.000001	1×10^{-6} or 1×10^{-6}	Millionth	micro-
1,000,000,000,000	1×10^{12} or 1×10^{12}	Trillion	tera-	0.000000001	1×10^{-9} or 1×10^{-9}	Billionth	nano-
1,000,000,000,000,000	1×10^{15} or 1×10^{15}	Quadrillion	peta-	0.000000000001	1×10^{-12} or 1×10^{-12}	Trillionth	pico-

However, to avoid confusion between the two systems, the numbers are often expressed simply and clearly by denoting the power of ten.

Incidentally, as discussed below, the exponent on the 10 is also called the logarithm to the base 10 ($\log_{10}$). So, for example, the logarithm to base 10 for 1 billion is 9. To multiply numbers, you simply add the logarithms or exponents to the base 10. For one billion times one billion, the calculation would be $9 + 9 = 18$, giving you 10^{18} .

To get a better grasp of large numbers you might want to consider planning to rob a bank. You plan to escape by driving immediately to the airport and hopping on a commercial flight. If you ask for \$1,000,000 in \$20 bills, how long would it take the cashier to count them out, and could you fit them in a bag you could carry? A good cashier could probably count one bill per second, so it would take 50,000 s. That is almost 14 h. You might miss your flight. The bills would take up a volume of a bit more than 27 ft^3 . You might already anticipate that this is not going to fit into the overhead bin on the airplane nor under the seat in front of you. In fact an ordinary suitcase holds less than 3 ft^3 so you would need 10 suitcases, and the airline will only accept two.

Alternatively, you could ask for \$100 bills, but have you ever tried to cash one? It would be more reasonable to ask for gold. At current prices, $\$1 \times 10^6$ is equal to 91 pounds of gold. This would fit neatly into a sturdy briefcase, but security might want to open it to make sure it's not uranium or plutonium for a bomb. If you try to check it through, the airline will want to charge for overweight luggage, and you can bet it will get lost. At this point you will probably have concluded that it would be easier to ask the bank to make a wire transfer of the money to your Swiss bank account.

One symbol you will see in discussions about the ocean is ‰. You already know that. % means percent, or parts in a hundred. The ‰ is read as per mille, meaning parts in a thousand. It is used in discussions of the salinity or saltiness of the ocean in which a kilogram ($1,000 \text{ g} = 2.20462262 \text{ lbs}$) of normal seawater contains about 34.5 g ($=1.21695 \text{ oz}$) of salt. Seawater's average salinity is said to be 34.5 ‰ . Note that you will get the same 34.5 ‰ if you convert ounces to pounds and divide that number by the weight of a kilogram expressed in pounds. The metric system seems much simpler, doesn't it?

By the way, if you are an aficionado of gin, like me, you are probably familiar with Hendrix Gin, which the makers claim to be preferred by 1 person in a thousand or 1% of gin drinkers. It's the cucumber that makes it special.

Here is a practical example of the importance of orders of magnitude: When I was a graduate student at Stanford University near San Francisco several of us had rented a house in Palo Alto, and we passed around cooking and refreshment duties. One member of our group was a

chemistry graduate student, who decided it would be a great idea to make that forbidden drink, absinthe. Absinthe contains wormwood and a supposedly psychoactive agent. It was famously consumed by many avant-garde painters and writers in the late 19th and 20th centuries, and social conservatives of the time blamed it for the progressive ideas of their adversaries. The drink was, until quite recently, banned in the United States. Our chemist had found a recipe for absinthe somewhere, and all we needed were grain alcohol and the necessary herbs. San Francisco has a number of herbalist shops, so we headed up to the big city. We selected the herbalist who had cat skins on display in his window, thinking he would certainly have everything we might need. Rather secretively our 'chemist' read off his list of items and their required amounts, one by one. The herbalist weighed out each item; all of them dried herbs, and poured them into envelopes. Then we got to wormwood, the crucial ingredient. The herbalist looked at us sternly and said "that's a hundred times more than you need." He seemed to have divined what we were up to. Our chemist replied "Well that's what our recipe calls for." "OK," said the herbalist after a bit of thought. "I'll sell it to you, but it's way, way too much."

We took our ingredients back to our house, and we carefully mixed them all up with the alcohol, according to the recipe. I think we allowed it to age about a week. Then came the test. One drop on the tongue and you couldn't taste anything else for hours. Wormwood has one of the bitterest tastes imaginable. Apparently we had made a mistake of about two orders of magnitude. Even diluted, it was awful. Incidentally, wormwood is not only one of the ingredients of absinthe, it is the flavoring in vermouth, though in concentrations many orders of magnitude less than what was in our concoction.

Orders of magnitude become very important when we think about time, especially the vastness of geologic time. When trying to imagine geologic changes on the surface of Earth we are talking about long, long, long periods of time. Unimaginable lengths of time. Millions of years. Geologists have adopted several abbreviations to save words. A thousand years is designated by ky, kyr, Kyr, and ka for Kiloyears (1,000 years). A million years can be designated by any of the following abbreviations: my, myr, or ma. Ma stands for millions of years ago. A billion years is designated by Ga.

2.4 Logarithms

In the discussion above you saw how exponents of the number 10 can be used to indicate the number of times to move the decimal point to the left or right. They indicate the number of times you have to multiply a number by itself to

get a given value. You read ' 10^3 ' as '10 to the third power.' They save a lot of space in writing out very large or very small numbers and make comparisons of numbers much easier.

However, there is another way of doing the same thing, through the use of 'logarithms.' Two scholars, Scottish Baron John Napier (1550–1617) and Swiss clockmaker Joost Bürgi (1552–1632), independently developed systems that embodied the logarithmic relations and, within years of each other, published tables for their use. But Napier published first, in 1614, and Bürgi published in 1620, so Napier gets the credit for inventing them. Also, Bürgi forgot to include instructions for the use of his tables of logarithms; they were published later.

A logarithm is the power to which a standard number, such as 10, must be raised to produce a given number. The standard number on which the logarithm is based is called, of all things, the base. Thus, in the simple equation $n^x = a$, the logarithm of a , having n as its base, is x . This could be written $\log_n a = x$. As an example from the preceding section about orders of magnitude, that equation might be $10^3 = 1,000$; written the other way it becomes $\log_{10} 1,000 = 3$. With logarithms to the base 10, simple orders of magnitude are very easy to figure out. What is not so easy to figure out is what the $\log_{10}$ of 42 would be. (You may recall from Douglas Adams' *The Hitchhiker's Guide to the Galaxy* that 42 is the answer to the question 'what is the meaning of life, the Universe, and everything?') To determine $\log_{10} 42$ you need to do some real work. When I was a student, you could buy books of tables of logarithms to the base 10, and look it up. So there. Now most calculators and computer spreadsheet programs, such as Excel, will do this for you. For your edification $\log_{10} 42$ is 1.623249. Then you will ask: why would anyone want to convert the numbers to logarithms anyway? A very simple reason: multiplying two numbers together is the same as adding their logarithms together. Better yet, dividing one number by another is the same as subtracting the logarithm of the second number from that of the first. Before the days of electronic calculators and computers, this was a very efficient way of multiplying and dividing large numbers, but most of us had to have a book of tables to do it.

Logarithms have crept into the way we describe a number of things. Logarithms to the base 10 are called 'common logarithms' and you already know how they are used. You may be aware that the acidity or alkalinity of a solution is described by its 'pH' which is a number ranging from 0 to 10. Now for the bad news: pH is the *negative* logarithm to the base 10 of the concentration of the hydrogen ion (H^+) in the solution. This means that a small number means there are lots of H^+ ions in the solution, and a large number means

that there are only a few. How's that for convoluted logic? Now for the good news, it should make sense later in the book when protons and electrons are discussed.

2.5 Logarithms and Scales with Bases Other than 10

Some other very useful logarithms don't use 10 as their base. Computers depend on electrical circuits that are either open or closed—two possibilities. So computers use a system with base 2, the 'binary logarithm.'

Then there is a magical number that is the base of a logarithm that will allow you to calculate compound interest, or how much of a radioactive element will be left after a given time or anything that grows or decays away with time. This base is an 'irrational number;' that is, it has an infinite number of decimal places. It starts out 2.7182818128459045... and goes on forever; it has a special name in mathematics, it is ' e '. Its discovery is usually attributed to Swiss mathematician Leonhard Euler in the 18th century, but it also appears, figured out to several decimal places, on Babylonian clay tablets. Logarithms with e as their base are called 'natural logarithms.' The uses of these magical logarithms will be discussed in later chapters. It comes back up again in the discussions of radioactive decay and the impact of the growth of the human population on our small planet. Incidentally, the repetition of 1828 at the beginning of the number has struck mathematicians as something very odd and raised the question whether other parts sequence might repeat at some point. But it has now been calculated to 869,894,101 decimal places and so far there have been no further significant repetitions.

2.6 Earthquake Scales

A good example is of the use of logarithms with a base other than 10 is when describing the intensity of earthquakes. This has recently caused considerable confusion in the press.

Earthquakes are events in which the ground moves. They were rather mysterious until the 1970s when it was realized that the surface of the Earth is constructed of large rigid plates that move with respect to each other. Most large earthquakes occur along the boundaries where these plates converge as one is forced down beneath the other, or in geological terminology, 'subducted.' Recent large earthquakes are shown in Fig. 2.5.

There are currently three different scales used to describe the intensity of earthquakes; two of these scales are logarithmic. In 2010 confusion about these scales was rampant as journalists tried to compare the January 10 earthquake in

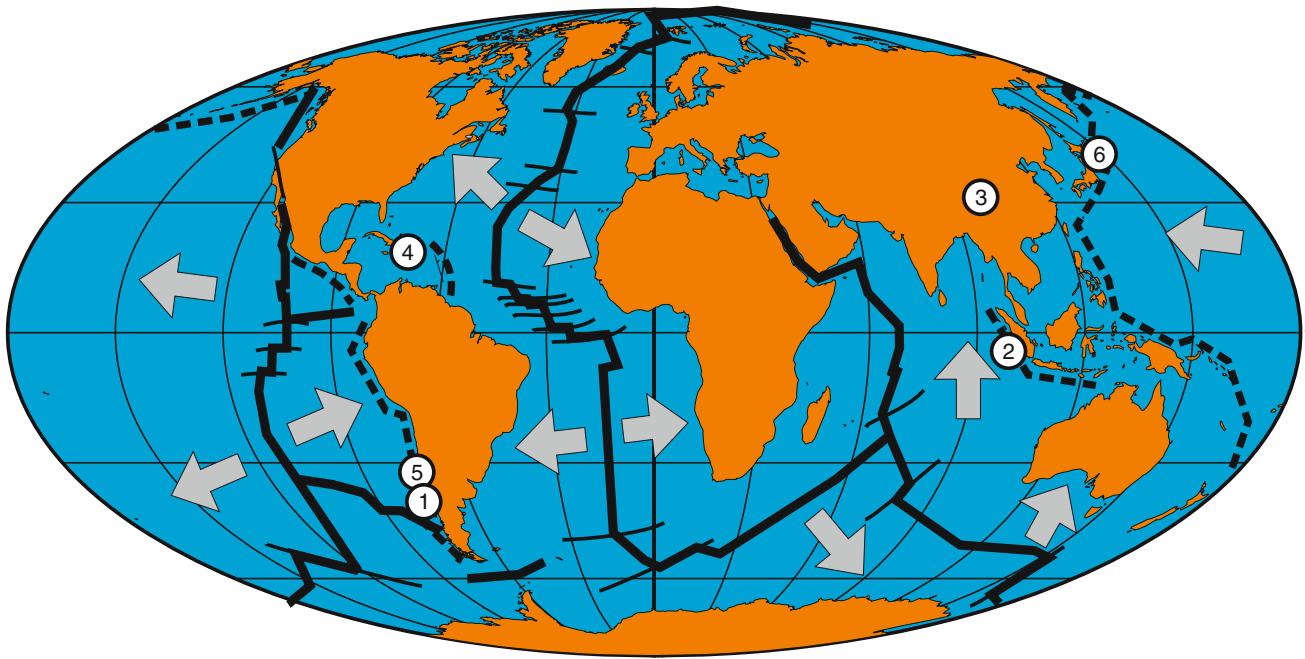


Fig. 2.5 Major plates of Earth's crust. The plates grow along the mid-ocean ridge system (*heavy black lines*) which is sometimes offset by 'transform faults' (*thin black lines*) where the plates slide past each other. Most large earthquakes occur where the plates converge (*heavy dashed lines*) and one is forced beneath the other, a condition geologists call 'subduction.' A few earthquakes occur due to stresses within the plates ('intra-plate' earthquakes). The sites of some recent major earthquakes are shown (M_W = Moment Magnitude Scale of earthquake intensity): 1 Valdivia, Chile, May 22, 1960, subduction, M_W = 9.5,

deaths = 5,700 (est.); 2 Sumatra, December 26, 2004, subduction, M_W = 9.2, deaths = 227,898, mostly by drowning from the ensuing tsunami; 3 Eastern Sichuan, China, May 12, 2008, intra-plate, M_W = 7.9, deaths = 87,587; 4 Haiti, January 12, 2010, M_W = 7.0, transform fault, deaths = 222,570; 5 Maule, Chile, February 27, 2010, subduction, M_W = 8.8, deaths = 577; 6 Tohoku, Japan, March 11, 2011, subduction, M_W = 9.0, more than 13,000 deaths, mostly by drowning from the ensuing tsunami

Haiti (7.0 M_W transform fault), which killed over 200,000 people, with the February 27 earthquake in Chile (8.8 M_W subduction) which killed less than 600 people.

The classification of intensity of earthquakes began in the latter part of the 19th century with a scale developed by Michele Stefano Conte de Rossi (1834–1898) of Italy and François-Alphonse Forel (1841–1912) of Switzerland. The Rossi-Forel scale was purely descriptive ranging from I, which could be felt by only a few people, through V, which would be felt by everyone, and might cause bells to ring, to X, which would be total disaster. It was modified and refined by the Italian volcanologist Giuseppe Mercalli (1850–1914) toward the end of the century, and a revision ranging from I to XII became widely accepted in 1902, just in time for the San Francisco earthquake; the city had some areas near the top of the scale. It has been modified a number of times since to become the 'Modified Mercalli Scale' with intensities designated MM I to MM XII based on human perceived movement of the ground and damage to structures. On this scale the Haiti earthquake ranged from MM XII at the epicenter near the town of Léogâne and MM VII in Port-au-Prince about 16 miles (25 km) to the east. The MM scale is purely descriptive of the damage.

In 1935, the seismologist Charles Richter (1900–1985) developed a more 'scientific' scale based on the trace of the earthquake recorded in a particular kind of seismograph, the Wood-Anderson torsion seismometer. (A seismograph is an instrument that measures the motion of the ground.) Originally developed for use in southern California, Richter's scale has become known as the 'local magnitude scale' designated M_L . It is based on logarithms to the base 10, so that an earthquake with M_L 7 is ten times as strong as one with an intensity of M_L 6. Richter and his colleague Beno Gutenberg estimated that on this scale the San Francisco earthquake of 1906 had a magnitude of about M_L 8. Unfortunately, the Wood-Anderson torsion seismometer doesn't work well for earthquakes of magnitude greater than M_L 6.8.

In 1979, seismologists Thomas C. Hanks and Hiroo Kanamori published a new scale, based on the total amount of energy released by the earthquake. Development of this new scale was made possible by more refined instruments and an increasingly dense network of seismic recording stations. The new scale, in use today, is called the 'Moment Magnitude Scale' (MMS) and is designated M_W . It is based on determining the size of the surface that slipped during an

earthquake, and the distance of the slip. It too is a logarithmic scale, but its base is 31.6. That is, an earthquake of M_W 7 is 31.6 times as strong as one of M_W 6.

On this scale the Haiti earthquake was M_W 7.0, and the Chile earthquake M_W 8.8. Most journalists had learned about the ‘Richter scale’ (M_L) when they were in school, and had never heard of the M_W scale. The result was that news reports comparing the Chile and Haiti earthquakes cited very different numbers to compare their intensity, indicating that the Chile quake was from 50 to 1,000 times more powerful. The confusion arose because of the different scales (M_W versus M_L) used by different sources to report the magnitude of the quake. In terms of the ground motion (M_L) the Chile earthquake was about 70 times stronger, but in terms of the actual energy released (M_W) it was 500 times as large as the Haiti earthquake.

Why were the death tolls so different? Because there had been no significant earthquakes in Haiti for over a century, no special precautions had been taken in constructing homes and larger buildings. Those built on solid rock received relatively little damage, but much of the city of Port-au-Prince had been built on unconsolidated sediments which amplified the shaking and caused many structures to collapse. The Haiti earthquake was the result of slow convergence of the North Atlantic and Caribbean tectonic plates.

Then, during the afternoon of March 11, 2011, Japan suffered an M_W 9 earthquake with an epicenter in the sea east of Tohoku. The earthquake was followed by a catastrophic tsunami. The death toll exceeded 13,000. It was one of the five largest earthquakes since 1900.

In contrast, there had been 13 earthquakes of magnitude M_W 7 or greater since 1973 along the southeastern Pacific margin. The 2010 epicenter was located about 230 km north of the magnitude M_W 9.5 Valdivia earthquake that occurred on May 22, 1960 and 870 km south of that of a magnitude M_W 8.5 earthquake that occurred on November 11, 1922. All of these and the many other smaller earthquakes in this region are a result of the convergence of the South American and Nazca tectonic plates.

2.7 The Beaufort Wind Force Scale

In 1805 Francis Beaufort (1774–1857), an Irish hydrographer and officer in the Royal Navy, devised a scale to relate wind conditions to their effect on the sails of a frigate, ranging from “just sufficient to give steerage” to “that which no canvas sails could withstand.” The scale became a standard for the Royal Navy’s ship’s log entries in the late 1830s. Then, in 1846, British astronomer and physicist Thomas Romney Robinson (1792–1882) built a device to accurately measure the velocity of the wind, an anemometer.

It consisted of four hemispherical cups attached to a pole, which would spin in the wind, and a device for determining the speed of rotation. The conversion from speed of rotation of the anemometer to wind speed took some time. The four-cup anemometer had the problem that when the concave cup was facing the wind on one side, the convex side of the cup was facing the cup on the other side. Nevertheless, in the 1850s the Beaufort scale was calibrated to the four-cup anemometer rotations reflecting wind speeds.

In 1906 George Clarke Simpson (1878–1965) issued his *Report of the Director of the (British) Meteorological Office upon an Inquiry into the Relations between the Estimates of Wind Force According to Admiral Beaufort’s Scale and the Velocities Recorded by Anemometers Belonging to the Office*. In this Report he shows that the measured wind speeds correspond closely to the Beaufort scale using the empirical relationship:

$$v = 1.87B^{3/2} \quad \text{or} \quad B = 0.659v^{2/3} \quad \text{or} \quad B = (2/3)v^{2/3}$$

where v is the wind speed in miles per hour at 33 ft above the sea surface (the average height of the deck of a frigate above the sea) and B is Beaufort scale number.

In metric terms this becomes

$$v = 0.836B^{3/2} \quad \text{or} \quad B = 1.127v^{2/3}$$

where v is the wind speed in meters per second at 10 m above the sea surface and B is Beaufort scale number.

In 1916, most sailing ships having been retired out of service, George Simpson, Director of the British Meteorological Office, made slight changes to the scale to better reflect how the sea behaved and he also extended it to land observations. The revision was standardized in 1923 and was subsequently improved to become more useful for meteorologists and communication with the general public.

In 1926 a Canadian physicist and meteorologist, John Patterson (1872–1956), devised a three-cup anemometer. Each cup produced maximum torque when it was at 45° to the wind flow. This new anemometer also had a more constant torque and responded more quickly to gusts than the four-cup anemometer.

With adoption by many countries of the metric system, with wind speeds expressed simply in m/s or km/h, the Beaufort scale has fallen out of use except for severe weather warnings to the public. In 1946 the Beaufort scale was extended, with forces 13–17 added for special cases, such as tropical cyclones. However, today the extended scale is used solely for typhoons affecting eastern Asia and its offshore islands (Table. 2.2).

The logarithmic base for these scales is independent of whether the units are imperial or metric and has the value 3/2 or 1.5. For example, $B = 4$ gives a wind speed of 6.7 m/s, B7

Table 2.2 The Beaufort Wind Scale, used to relate wind and sea state conditions on the open sea

BN	Wind conditions	Maximum wind speed			Maximum wave height		Wave description
		Knots	mph	m/s	Ft	m	
0	Calm	0.6	0.7	0.3	0	0	Flat
1	Light air	3.0	3.4	1.5	1	0.2	Ripples w/o crests
2	Light breeze	6.4	7.4	3.3	2	0.5	Small wavelets
3	Gentle breeze	10.6	12.2	5.5	3.5	1	Large wavelets, crests begin to break, few whitecaps
4	Moderate breeze	15.5	17.9	8	6	2	Small waves, breaking crests, frequent whitecaps
5	Fresh breeze	21	24.1	10.8	9	3	Moderate waves, many whitecaps, some spray
6	Strong breeze	26.9	31	13.9	13	4	Long waves, white foam crests, some airborne spray
7	Near gale	33.4	38.4	17.2	19	5.5	Sea heaps up, foam blown into streaks, airborne spray
8	Fresh gale	40.3	46.3	20.7	25	7.5	Moderately high waves forming spindrift, considerable airborne spray
9	Strong gale	47.6	54.8	24.5	32	10	High waves, crests sometimes roll over, dense foam, airborne spray reduces visibility
10	Storm	55.3	63.6	28.4	41	12.5	Very high waves with overhanging crests, foam on wave crests give sea a white appearance
11	Violent storm	63.4	72.9	32.6	52	16	Exceptionally high waves, very large patches of foam cover sea surface, airborne spray severely reduces visibility
12	Hurricane–typhoon	>	>	>	>52	>16	Huge waves, sea completely white with foam, air filled with driving spray greatly reducing visibility
13	<i>Typhoon</i>	80	92	41.4	–	–	–
14	<i>Typhoon</i>	89	103	46.1	–	–	–
15	<i>Typhoon</i>	99	114	50.9	–	–	–
16	<i>Severe typhoon</i>	108	125	56.0	–	–	–
17	<i>Severe typhoon</i>	118	136	61.2	–	–	–

BN Beaufort scale number

is 15.5 m/s, B11 is 30.5 m/s—all squarely in the middle of the range for each class. Using this formula the highest wind thus far recorded in a tropical storm, a wind gust of 113.2 m/s (220 kt; 253 mph) on 10 April 1996 at 64 m above sea level on Barrow Island off Australia during Tropical Cyclone Olivia would be B26 in a projection of the scale.

2.8 Extending the Beaufort Scale to Cyclonic Storms

As will be discussed in detail in Chap. 24 on atmospheric circulation, cyclones are storms that develop from atmospheric low pressure systems. Responding to Earth's rotation, air at in the lower part of the atmosphere spirals in toward the center of low pressure. It forms a gyre rotating counterclockwise in the Northern Hemisphere, and clockwise in the Southern Hemisphere. Intense cyclonic storms form both in the tropics and at high latitudes.

In 1971 meteorologist Tetsuya Fujita of the University of Chicago and Allen Pearson, head of the U.S. National Severe Storms Forecast Center introduced a scale for rating the intensity of tornados in the United States. It is based primarily on the damage to different kinds of human-built structures and vegetation but includes estimates of the wind velocities. Therefore the Fujita (or Fujita-Pearson) scale is neither linear nor logarithmic with respect to the estimated wind speeds.

In 1973 wind engineer Herbert Saffir and meteorologist Robert Simpson, Director of the U.S. National Hurricane Center, published a scale (acronym: SSHS = Saffir-Simpson Hurricane Scale, or SSHWS Saffir-Simpson Hurricane Wind Scale) for alerting the public to the danger posed by a hurricane according to its intensity. They chose the maximum sustained surface wind speed [defined as the peak 1 min wind at the unobstructed standard meteorological observation height of 10 m (33 ft)] associated with the storm as the basis of the scale. The categories are based on the perceived

Table 2.3 The TORRO tornado intensity scale

TORRO scale (B scale equivalent)	Wind speed			Tornado description	Damage description
	Mph	km/h	m/s		
FC				Funnel cloud aloft (not a tornado)	No damage to structures, unless on tops of tallest towers, or to radiosondes, balloons, and aircraft. No damage in the country, except possibly agitation to highest tree-tops and effect on birds and smoke
T0 B8	39–54	61–86	17–24	Light	Loose light litter raised from ground-level in spirals. Tents, marquees seriously disturbed; most exposed tiles, slates on roofs dislodged. Twigs snapped; trail visible through crops
T1 B10	55–72	87–115	25–32	Mild	Deckchairs, small plants, heavy litter becomes airborne; minor damage to sheds. More serious dislodging of tiles, slates, chimney pots. Wooden fences flattened. Slight damage to hedges and trees
T2 B12	73–92	116–147	33–41	Moderate	Heavy mobile homes displaced, light caravans blown over, garden sheds destroyed, garage roofs torn away, much damage to tiled roofs and chimney stacks. General damage to trees, some big branches twisted or snapped off, small trees uprooted
T3 B14	93–114	148–184	42–51	Strong	Mobile homes overturned/badly damaged; light caravans destroyed; garages and weak outbuildings destroyed; house roof timbers considerably exposed. Some of the bigger trees snapped or uprooted
T4 B16	115–136	185–220	52–61	Severe	Motor cars levitated. Mobile homes airborne/destroyed; sheds airborne for considerable distances; entire roofs removed from some houses; roof timbers of stronger brick or stone houses completely exposed; gable ends torn away. Numerous trees uprooted or snapped
T5 B18	137–160	221–259	62–72	Intense	Heavy motor vehicles levitated; more serious building damage than for T4, yet house walls usually remaining; the oldest, weakest buildings may collapse completely
T6 B20	161–186	260–299	73–83	Moderately devastating	Strongly built houses lose entire roofs and perhaps also a wall; windows broken on skyscrapers, more of the less-strong buildings collapse
T7 B22	187–212	300–342	84–95	Strongly devastating	Wooden-frame houses wholly demolished; some walls of stone or brick houses beaten down or collapse; skyscrapers twisted; steel-framed warehouse-type constructions may buckle slightly. Locomotives thrown over. Noticeable de-barking of trees by flying debris
T8 B24	213–240	343–385	96–107	Severely devastating	Motor cars hurled great distances. Wooden-framed houses and their contents dispersed over long distances; stone or brick houses irreparably damaged; skyscrapers badly twisted and may show a visible lean to one side; shallowly anchored highrises may be toppled; other steel-framed buildings buckled
T9 B26	241–269	386–432	108–120	Intensely devastating	Many steel-framed buildings badly damaged; skyscrapers toppled; locomotives or trains hurled some distances. Complete debarking of any standing tree-trunks
T10 B28	270–299	433–482	121–134	Super	Entire frame houses and similar buildings lifted bodily or completely from foundations and carried a long or large distance to disintegrate.
T11 B30	>300	>483	>135	Colossal	Steel-reinforced concrete buildings may be severely damaged or almost obliterated

potential for damage so, again the scale is neither linear nor logarithmic. It is used in the United States and parts of the Caribbean.

In 1974 Terence Meaden of Oxford University in England proposed extending the Beaufort scale to include tornados, using the $3/2$ Power relationship to develop a scale T0 to T10, with T0 equal to B8. He organized the Tornado and Storm Research Organization (TORRO) which has been

active in documenting and cataloging storms in Britain and on the European mainland.

The relationship between the two scales is

$$B = 2(T + 4) \text{ and conversely : } T = (B/2 - 4).$$

Table 2.3 shows the TORRO scale and the terminology associated with it. The descriptions of damage at increasing intensity levels are in delightfully colloquial English.

2.9 Calendars and Time

Next to counting and keeping track of objects and wealth, the most important use of numbers in the ancient world was probably to keep track of time. The ultimate basis for time is astronomical: such as the length of a day, the phases of the Moon (the length of a month), and the length of a year. The need to track longer periods of time led to the development of calendars. In early human history the most important times to keep track of were years, seasons, and days. Smaller units of time were not needed until societies become more complex.

The most important thing to keep track of was the seasons, to be able to anticipate the changes in climate though the course of the year. The seasons are caused by the changes in energy received by different parts of Earth during the year due to the 23.5° tilt of its axis of rotation relative to the plane of its orbit around the Sun (Fig. 2.6). The hemisphere tilted towards the Sun will receive more direct sunlight and heat (photons) and therefore be warmer, the hemisphere tilted away from the Sun will receive photons spread over a larger surface area and so be cooler. Seasons are not, as some people seem to believe, caused by the varying distance of the Earth's orbit from the Sun; if this were the case then both hemispheres would experience the same season at the same time of the year rather than at opposite times of the year as they do in reality. Figure 2.6 shows how this produces the seasons and explains the meaning of the terms 'solstice' and 'equinox.'

Here it worth mentioning that the longest-lived civilization, that of the Egyptians, which lasted for about 3,500 years, only recognized three seasons, not four. At the latitude of the Sahara and Arabian deserts, the temperatures do not vary greatly throughout the year, and rainfall is a rare occurrence and not seasonal. The Egyptian calendar had a year that was 365 days long, with 12 months, each having 30 days followed by five extra days at the end of the year. Each month was divided into 3 weeks of 10 days each. The big event was the annual flooding of the Nile. The three Egyptian seasons were *Akhet* (June–September), the season of inundation by flooding of the Nile; *Peret* (October–February), the season after the floodwaters receded, leaving behind a fresh layer of rich, black soil which was then plowed, planted and crops grown, and *Shemu* (March–May), when the crops were harvested.

The source of the Nile is far to the south, about 3,500 km (2,100 miles) away, in the region of Lake Victoria, and unknown to the ancient Egyptians. Lake Victoria wasn't known to the outside world (Europeans) until its discovery by Richard Burton's companion explorer John Speke in 1858 on their expedition to find the fabled lakes of eastern Africa. The rainfall there is highest in March through May, about 3 months before the flooding of the Nile in Egypt. To

the ancient Egyptians, the flooding of the Nile was a miraculous annual event.

The construction of the Aswan Dam in the 1960s has been one of the 20th century's great experiments in geo-engineering. It would generate electricity and regulate the flow of the river, but it has had unintended regional consequences. The sediment carried by the river is now trapped behind the dam. The annual flooding of Egypt with its delivery of fresh fertile mud that could be plowed into the soil has ceased. So now the farmers use fertilizers, some of which runs off into the now nearly stagnant river causing blooms of algae that kill the fish. The supply of Nile sediment that built the highly populated delta has been entirely cut off, so that coastal erosion is now a major problem. Because Lake Nasser, created by the dam, is in one of the Earth's regions of highest evaporation, with a rate of more than 2 m (about 7 ft) per year, the flow of the Nile into the Mediterranean Sea has almost ceased. Without the Nile outflow, the salinity of the Eastern Mediterranean has been increasing, severely impacting the fisheries as far away as Turkey. Geoengineering can have unexpected repercussions.

But back to calendars. Some calendars, such as the Gregorian calendar used throughout the world today, are based on the solar cycle. Others, such as the traditional Islamic calendar, are based on lunar cycles. Still others, such as the Hebrew, Hindu, and Chinese calendars are based on both. The solar and lunar cycles closely coincide every 18.6, usually rounded to 19 years (see Fig. 2.7).

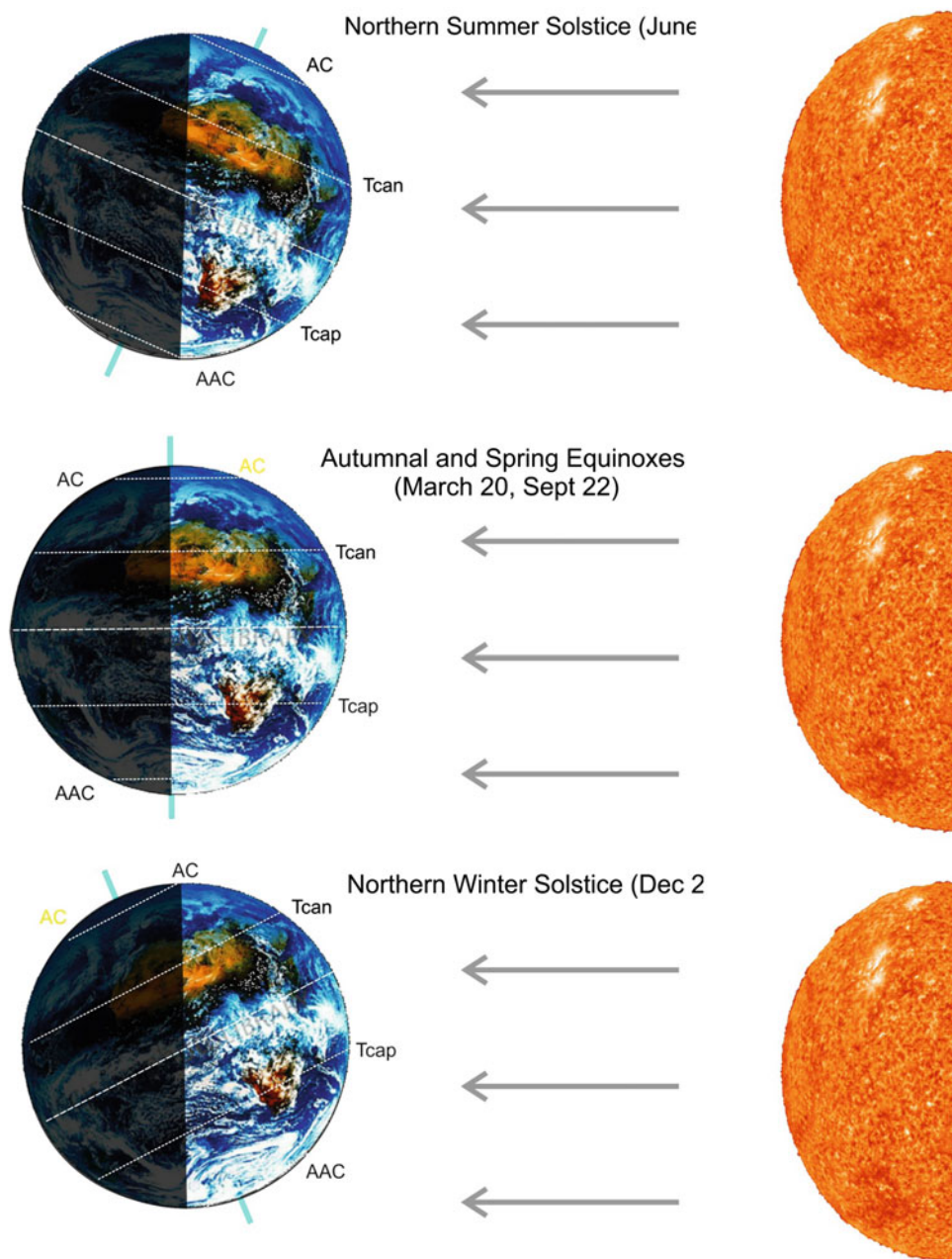
The Egyptians knew about the north–south motion of the Sun through the course of the year, probably using poles and then obelisks as sundials, as discussed below and shown in Fig. 2.8.

Now we need to define what we mean by "year." The one you are probably thinking of is the 'tropical year' (or 'equinoctial year' or 'solar year'). It is defined as the time from one March equinox, when the Sun is over the Equator moving northward, to the next. The mean value is 365.2422 days. Not to alarm you, but there are other kinds of 'year' that take the slow changes in Earth's orbit into account. We will get to those later in this book; they account for the changes in our planet's climate that resulted in the ice ages.

But there is also a 'lunar year' based on the cycles of the Moon. A synodic month is the time from one new Moon to the next. It roughly coincides with the menstrual cycle of women, which averages about 28 days. The synodic month ranges from 29.27 to 29.84 days with a mean of 29.53059 days. There are 12 synodic months of 29.53 days, giving a lunar year 354.36708 days, so a lunar year of 12 lunar months is about 10.88 days shorter than a solar year. Figure 2.7 shows the difference between solar and lunar years.

Starting dates of calendars differ: the Hebrew calendar is based on their traditional date for the creation of Adam. The

Fig. 2.6 The seasons are due to the 23.5° tilt of Earth's axis of rotation relative to the plane of its orbit around the Sun. The solstices are the times when the Sun is at its maximal northern or southern position in the sky. The equinoxes are when the Sun is over the Equator and the lengths of day and night are equal. Nomenclature is opposite in the two hemispheres. The *white dashed lines* are, from north to south: Arctic Circle (66.5° N), Tropic of Cancer (23.5° N), Equator (0°), Tropic of Capricorn (23.5° S), and Antarctic Circle (66.5° S)



Gregorian year 2015 is the year 5775 on the Hebrew calendar. The Hindu calendar begins with an alignment of the planets in 3102 BCE; Gregorian 2015 is Hindu 5117. The Islamic calendar starts with the Hijra (Hegira), the flight of Mohammed from Mecca to Yathrib, now known as Medina; Gregorian 2015 is Islamic 1436. But to really understand what has happened with our measurement of time we need to go back a couple of thousand years, to ancient Rome.

The Romans had a year of 355 days. The original calendar was attributed to Romulus, the (mythical) youth who founded Rome on April 21 of the year 1 AUC. AUC stands

for *ab urbe condita*, meaning the time 'from the founding of the city' (Rome). 1 AUC corresponds to 753 BCE.

The original Roman calendar was divided into 10 named months: *Martius*, *Aprilis*, *Maius*, *Junius*, *Quintilis*, *Sextilis*, *September*, *October*, *November*, and *December* plus two unnamed months representing the winter (when not much happened back then). The year began on *Martius* (March) 1. Eventually, the Romans settled on names for the two winter months, inserting *Januarius* and *Februarius* before *Martius*. Now you know why December (literally the tenth month) is the twelfth month of the year. Good cocktail party stuff.

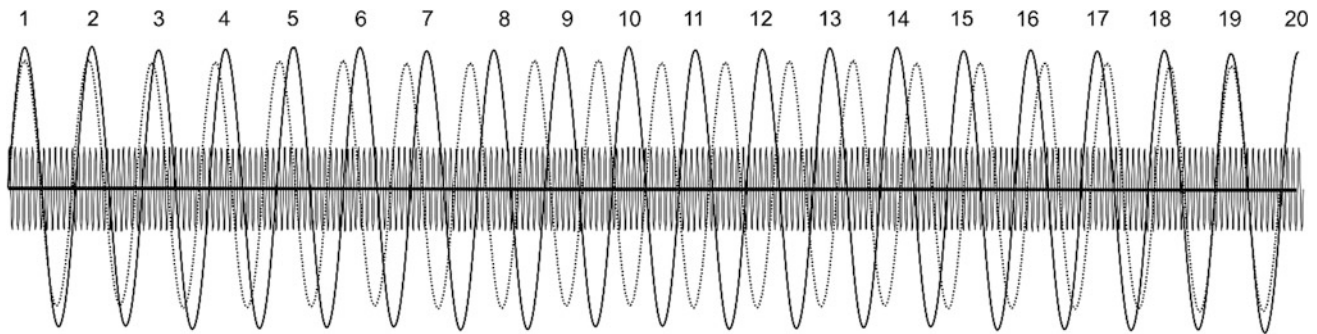


Fig. 2.7 Comparison of tropical (solar, *solid line*), lunar (*dotted line*) years, and lunations (lunar months, the short cycles shown). The solar year is 365.242189 days; lunar year is 354.36708 days; average

lunation (lunar month) is 29.53059 days. Topical and lunar years closely coincide every 18.6 years

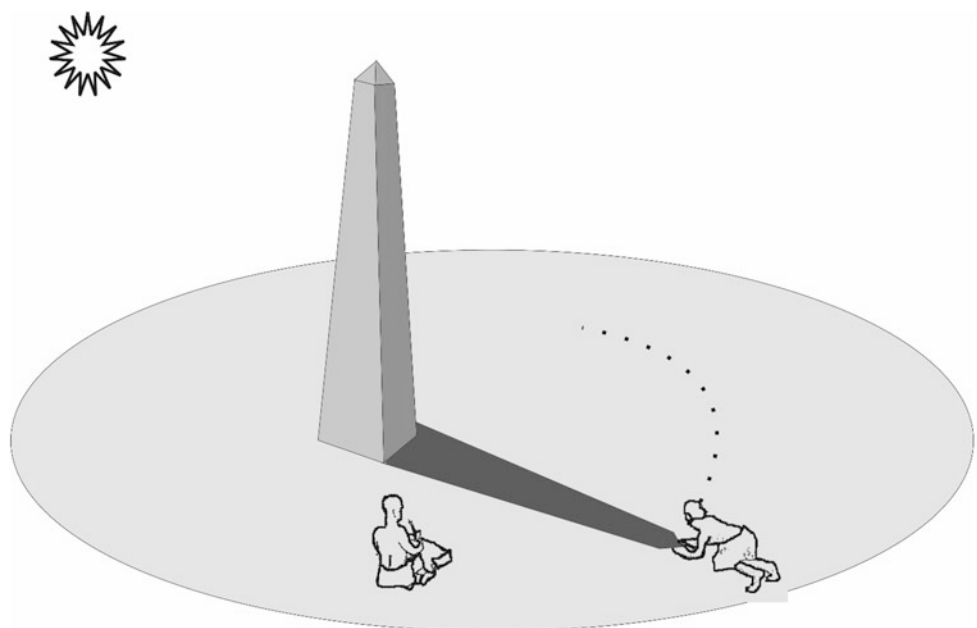
The year of 355 days meant that the seasons gradually shifted relative to the months. So an extra month (*Inter-calaris*) was inserted from time to time to keep the calendar in sync with the seasons. There was no specific rule for when to do it; just whenever it seemed like a good idea.

By the year 707 AUC (46 BCE), the seasons had drifted so far off from the months that the Roman dictator Julius Caesar took the bull by the horns and revised the calendar. By then it was known that the solar year was about 365.25 days. To correct the problem with the seasons, Caesar declared that 707 AUC would be 445 days long. The new Julian calendar went into effect the next year (708 AUC or 45 BCE). This calendar used 365 days for 3 years, followed by a fourth year with 366 days. The months alternated between 31 and 30 days in length, except for *Sextilis* which had 31 days, and *Februarius* which had 28 days for 3 years and 29 days the fourth year. The year was reset to begin on

Januarius 1. This system was to continue in perpetuity. The seventh month (*Quintilis*) was renamed *Julius* (July) to honor the creator of the new calendar. The middle of each month was called the *Ides*. It was on the Ides of March 709 AUC (44 BCE) that Julius Caesar was assassinated by a conspiracy of senators who opposed his dictatorial ways.

Julius Caesar had no legitimate children. In his will, he named his adopted son, Gaius Octavius, to be his successor. There ensued a series of disagreements and intrigues over the succession, involving, among others, Mark Anthony and Cleopatra, the inspiration of many novelists and playwrights. It all makes for great entertainment. Octavius became known as Octavian, and in 726 AUC (27 BCE) he became the first Emperor of Rome assuming the lofty name of Augustus. He thought the Julian calendar was such a good idea that he let the eighth month (*Sextilis*) be renamed after himself, *Augustus*, which became our August.

Fig. 2.8 Using an obelisk as a sundial. By plotting points each day the solstices and equinoxes would become evident



In Julius Caesar's time the winter solstice (*solstitium*, from *sol*, meaning Sun, and *sister*, meaning to come to a stop and stand still) was on December 25. The winter solstice is the time (in the northern hemisphere) when the Sun reaches its southernmost point in the sky and starts its return northward. Everyone in the northern hemisphere celebrated the solstice in ancient times. For the Romans it marked the time when the Sun god Sol was reborn. The week preceding the solstice, December 17 through 23 was a wild week of debauchery known as the *Saturnalia*. Over time it was moved to end on December 25, coinciding with the winter solstice. The week after the solstice continued the period of celebration and revelry so there was plenty to repent for at the beginning of the New Year, On January 1; everyone could make resolutions to not drink so much the next time, making them feel better about themselves. Julius Caesar had been a clever leader.

Eventually, came the Christians. They needed a date to celebrate the Resurrection of Christ. At the Council of Nicaea in 325 CE the Resurrection was set as the Sunday following the first full Moon after the northern hemisphere vernal (spring) equinox. The equinox is a time of equal lengths of day and night (*aequinocetium*, from *aequus* [equal] and *nox* [night]). The newly designated day, sometime after the middle of March, became independent of the Hebrew Passover. It was named Easter, after the pagan goddess of spring, Oestara.

To simplify determining the dates of the movable feasts the church adopted a new Ecclesiastical Calendar, a calendar based on the lunisolar cycle. In it the vernal equinox and the full Moon were not determined by astronomical observation but the vernal equinox was simply assumed to fall on the 21st day of March, and the full Moon (known as the Ecclesiastical Full Moon) was fixed to be 14 days after the beginning of the Ecclesiastical Lunar Month (known as the Ecclesiastical New Moon) The relevant Ecclesiastical New Moon (the Pascal New Moon) falls on or next after March 8. Depending on weather conditions and how good your eyes might be, the new Moon (total darkness) can vary by as much as 4 days. To make matters more confusing, the New Moon was determined not by when it reflects no sunlight, but upon the first appearance of a thin crescent. Easter falls on the Sunday after the Ecclesiastical Full Moon, not necessarily the real full Moon.

Then, in 350 CE Pope Julius I set December 25th, the traditional day of pagan festivities celebrating the winter solstice—as the day of celebration of the birth of Christ.

The Roman week had 8 days. The Babylonian week, adopted by the Hebrews, had seven. It was the Roman Emperor Constantine, a convert to Christianity in 330 CE, who introduced the 7 day week in the fourth century. The custom spread throughout much of Europe.

In about 525 CE Pope John I figured the birth of Christ to have been in 753 AUC, which he renamed 1 AD (Anno

Domini). Earlier years have then become designated as BC (Before Christ) and there was no year 0, and unfortunately the Pope's calculations were wrong. According to the Bible, Christ was born during the reign of Herod the Great which ended in 749 AUC (now 4 BC). Most modern-day biblical scholars place the time of the nativity sometime between 747 and 749 AUC (6 and 4 BC/BCE).

Keeping time went more or less well for over a thousand years. However, the Julian calendar year of 365 days and 6 h was too short by 11 min. By the 16th Century this tiny error had made the calendar a mess. The dates of the solstices and equinoxes were off by 10 days.

In 1582 Pope Gregory cleaned up the mess by deleting 10 days from the calendar and proposing omitting a leap year every 400 years. This revision became known as the Gregorian calendar. In most Roman Catholic countries in 1582, Thursday, October 4th, was followed by Friday October the 15th. Other countries retained the Julian calendar.

Leaving out 10 days had unexpected consequences. It moved January 1, the beginning of the New Year, leading to confusion over the year in which something happened. The change to the Gregorian calendar did not occur until almost two centuries later in the United Kingdom. In London in 1757, Wednesday, September 2nd, was followed by Thursday, September 14th. Dates in Britain and its colonies before then, using the Julian calendar are referred to as "Old Style;" corrected to correspond to the Gregorian calendar as "New Style." Thus, the execution of Charles I was recorded by the Parliament as happening on 30 January 1648; the date is now referred to as Old Style. In modern accounts this date is usually shown as "30 January 1649 (New Style)." Similarly, Isaac Newton died on the 20th of March, 1726 (Old Style) which corresponds to the 31st of March, 1727 (New Style). Can you figure out how old he was when he died?

In Russia, the Great October Socialist Revolution of 1917, also known as the Bolshevik Revolution, was the seizure of state power by armed insurrection in Petrograd (which then became Leningrad, now known as St. Petersburg). In Russia this historic event happened on October 25, 1917, but in London, it was recorded as occurring on November 7. Britain was using the Gregorian calendar while Russia was still using the Julian calendar. Russia switched to the Gregorian calendar in 1918. Greece adopted the "new" calendar in 1923, Turkey in 1927. It was finally air travel that caused the Gregorian calendar to become accepted worldwide.

Needless to say, because calendar reform took place at different times in different countries local records for temperature, rainfall, and other weather/climate conditions need to be checked to determine the proper date.

It should be obvious that history based solely on dates without knowing what calendar was being used can be quite a mess. This applies to weather events as well as everything else.

At about the same time that Pope Gregory was convening his council of experts, there was another attempt at calendar reform underway. Joseph Justus Scaliger (1540–1609) was a Calvinist Protestant (Huguenot) cleric who had just missed being caught up in the St. Bartholomew's Day massacre in 1572 when as many as 30,000 Huguenots in France lost their lives. Sensing that trouble was afoot, he had fled to Geneva. When he returned he moved into the castle of his friend Louis de Chasteigner, Lord of La Roche-Posay, in western France staying there from 1574 to 1594. Scaliger was interested in ancient history and wanted to produce a calendar that would be consistent through time to allow him to understand the timing of historic events. He was aware of the problem that some years had different lengths, as well as the problem that there was no year 0 in the Christian version of the Julian calendar. He wanted his calendar to go back in time far enough to include all of the history of human civilization. He published his eight volume work proposing the term Julian Period, *Opus novum Emendatione Temporum*, in 1583.

Scaliger used three cycles to determine the length of one grand cycle of time which he called the Julian Period:

- (1) The 19 year cycle for coincidence of solar years and lunations.
- (2) The 28 year cycle for repetition of days of the week throughout the year.
- (3) The 15 year Roman census cycle—The so-called 'Roman Indiction.'

Multiplying these together ($19 \times 28 \times 15$) Scaliger got 7980 years or 2,914,695 days. Scaliger rather arbitrarily set the starting time for the Julian Period at noon on January 1, 4713 BCE, which he thought was old enough to include all of human history, but he did not specify the geographic location for this noon. There were no time zones in those days. Until recently GMT (Greenwich (England) Mean Time), which was established in 1675, was used as the international standard for Scaliger's time system. GMT has now been replaced by UTC (Coordinated Universal Time) as the primary standard by which nations around the world consistently record and regulate time. The UTC system corrects for the tiny variations in GMT caused by changes in Earth's rotation rate, and other factors. UTC is sometimes abbreviated Z and called "Zulu time."

Because of the length of year problem, the time count in UTC is in days. This time is called the Julian date reflecting Scaliger's naming convention. Sciences requiring exact timing of events, such as astronomy, use this calendar. Thus the time when human beings (Neil Armstrong in particular) first set foot on the Moon is recorded as 2:56 UTC on July 21st, 1969. The Julian date for this event is 2440423.622222.

Yet another time convention is to use the UTC time and day number of the year. In this system (used by NASA among other institutions). Armstrong's Moon-touching date is 1969201 2:56. You can see these dates, sometimes abbreviated to just the day in the titles used on NASA's space photographs.

There have been additional, not-so-successful attempts at calendar innovation. In 1789 French revolutionaries tried to carry their enthusiasm for the number 10 to timekeeping. Their new calendar consisted of twelve 30 day months: *vendémiaire*, *brumaire*, *frimaire* (autumn); *nivôse*, *pluviôse*, *ventose* (winter); *germinal*, *floréal*, *prairial* (spring); *messidor*, *thermidor*, *fructidor* (summer). Each of the months consisted of three 10-day 'weeks' called *décades*. The names of the 10 days of the *décade* were simply numbered: *primidi*, *duodi*, *tridi*, *quartidi*, *quintidi*, *sextidi*, *septidi*, *octidi*, *nonidi*, *décadi*. The extra 4–6 days needed to fill out a year become holidays added at the end of the year. The day was divided into 10 h each with 100 min and the minutes divided into 100 s each. This innovative but deeply flawed calendar did not last long. The rest of the world continued to prefer the ancient Babylonian system of using 60s as the basis for timekeeping.

What about units of time smaller than the day? The day is naturally divided into times before the Sun is at its highest point in the sky, noon, and after: morning and afternoon. As societies developed in complexity it became useful to have smaller units of time. This can be done simply by following the shadow of a vertical pole on the ground. The vertical pole or other shadow-casting object is called a "gnomon." The Babylonians and Egyptians divided the day into 12 units, six for sunrise to noon, and six from noon to sunset. These units are now our hours.

We define a day as the length of time from one midnight to the next. This is a solar day, 86,400 s. But it is not a 360° rotation of the planet, but $360^\circ 59' 9.6''$. This is because Earth's motion in its orbit around the Sun is the same as the direction of its rotation on its axis, counterclockwise as seen from above the North Pole. A full 360° rotation, a sidereal day, takes only 86,164 s.

If you follow the path of the tip of the shadow of the gnomon over the course of the year, you can determine the days of the solstices and equinoxes as the Sun moves north and south. This is how all these things were worked out in ancient times. An obelisk makes a very good gnomon, the taller the better, and Egypt, with its often cloudless skies, was able to develop a very fine system of time keeping. The gnomon can even be used for timekeeping at night. At night you can position yourself so that the North Star, Polaris, is directly over the gnomon (or in Egypt, right on the tip of the obelisk) and mark time through the night by the motion of the other stars around it.

I once asked George Swenson, an astronomer and close friend when I was at the University of Illinois, how the ancients were able to make good astronomical measurements without a telescope. The answer was simple, if you don't have a lens to magnify things, you can use a longer baseline to get the same result. Sighting on a star's position over the tip of an obelisk on the opposite side of the Nile Valley would allow the observer to make very fine measurements of its motion. You can imagine that with such a long baseline the observer would have to keep moving to keep up with the motion of the star.

The Sun shadow method of keeping time developed into the sundials, used by the Egyptians, Greeks, Romans, and throughout Europe until the invention of mechanical clocks in the 17th century.

To make measurements of units of time shorter than an hour, some sort of a clock was needed. A clock needs two things: (1) a regular, constant, repetitive process to mark off equal units of time, and (2) some means of keeping track of the accumulated number of units of time.

The earliest of these devices were "water clocks" using a steady flow of drops of water to fill or empty a basin. Keeping track of the time was done by means of marks such as scribed lines on the side of the basin. The trick was to ensure that the rate of the drops was constant, a problem never completely solved. The accuracy of water clocks was limited.

A pendulum is a much better time keeping device, because its period depends only on its length and not on the size of the arc through which it swings but because of friction, the pendulum needs to be resupplied with energy to keep it working. This is done by a mechanism called an 'escapement.' The escapement transfers energy, often from suspended weights or a coil spring, to the pendulum. It has a forked pallet that alternately checks and releases a toothed wheel imparting the energy in pulses.

Galilei Galileo conceived the idea of a pendulum clock with an escapement around 1637, but died before it could be built. A working pendulum clock was invented by Dutch mathematician and physicist Christiaan Huygens in 1656. Later the pendulum was replaced by a spring with an escapement, making pocket and wristwatches possible. Since the 1950s timekeeping has been done with 'atomic clocks,' using the electromagnetic spectrum of atoms as frequency standards. There will be more about clocks in the discussion of longitude in the next chapter.

2.10 Summary

Mathematics is a way of keeping track of things and organizing information. It took thousands of years for systems of easily manipulated numbers to be developed. The simple

mathematical operations we know as arithmetic had their origins many thousands of years ago. We used to think that it was the Greeks in the first few hundred years BCE who developed mathematics beyond arithmetic, but recently we have learned that the more complex manipulations we call algebra were developed in Mesopotamia over 4000 years ago. The number zero, a symbol which stood for 'nothing,' was a special case. Although essential for solving many mathematical problems it was not introduced into Europe until about a thousand years ago.

Scientists deal with things that range in size from the universe to parts of atoms and use shorthand expressions, exponents and logarithms to keep written numbers manageable.

The need to keep track of time, especially the changing seasons through the course of the year, led to the development of calendars, but there were many obstacles and pitfalls along the way. Julius Caesar modified the older Roman calendar recognizing the year to be about $365\frac{1}{4}$ days long. The Julian calendar worked well for almost 1500 years, but its year was too short by 11 min. By the middle of the 16th century it was clearly out of sync with the seasons. Pope Gregory reformed the calendar in the 16th century, but many countries were slow in accepting the new calendar. It was air travel that forced its acceptance as a worldwide standard. And although used throughout the world today, the Gregorian calendar has a flaw, it has no year zero.

Accurate clocks were not developed until the middle of the 17th century. Precise timekeeping opened new vistas not only for scientific investigations but for determining the location of ships at sea as you will learn in the next chapter.

A Timeline for this chapter:

Year	Event
Way back there	Humans devise a system of numbers with base 10
~4000 BCE	Sumerians devise a system of numbers with base 60
~1900 BCE	Babylonians using base 60 number system determine that $\sqrt{2}$ is about 1.41421296
~1800 BCE	Egyptian textbook shows how to do arithmetic
~350 BCE	Aristotle defines mathematics as "the science of quantity"
753 BCE	Rome is founded on April 21 of Year 1 of the AUC (<i>ab urbe condita</i>) calendar
46 BCE = 707 AUC	Julius Caesar revises the Roman AUC calendar to have 365 days in a year and to add a day every fourth year. To get the seasons back in sync the year 707 AUC had 445 days. The revision is known as the Julian calendar. He renames the seventh month <i>Julius</i> (July)

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Year	Event
44 BCE	On the Ides of March, Julius Caesar is assassinated
27 BCE	Caesar's successor takes the name Augustus and renames the eight month in his honor— <i>Augustus</i>
325	The Council of Nicea sets the day of the Resurrection of Christ to be the Sunday following the first full Moon after the northern hemisphere vernal equinox, becoming independent of the Hebrew Passover. It was named Easter, after the pagan goddess of spring, Oestara
350	CE Pope Julius I set December 25th, the traditional day of pagan festivities celebrating the winter solstice—as the day of the birth of Christ
525	Pope John I reckoned the birth of Christ to have been in 753 AUC, which he renamed 1 AD (Anno Domini). Earlier years then became designated as BC. There was no year 0
825	Algebra is introduced by Baghdad mathematician Abu Ja'far Muhammad ibn Musa al-Khwarizmi in his book on equations <i>Al Kitab Fi Hisab Al Jabr Wa Al Muqabala</i>
1202	Leonardo Bonacci (Fibonacci) introduces zero to Europe
1582	Pope Gregory, in order to get the seasons back in sync, deletes 10 days from the Julian calendar. The new calendar is called the Gregorian calendar
1583	Joseph Scaliger publishes <i>Opus Novum Emendatione Temporum</i> introducing the Julian Period which began on January 1, 4713 BCE, and counts in days. Used by astronomers today
1614	John Napier publishes <i>Mirifici logarithmorum canonis description</i> with tables of logarithms
1620	Joost Bürgi publishes <i>Arithmetische und Geometrische Progress Tabulen</i> but forgets to include instructions on how to use the tables of logarithms
1633	Galileo Galilei's trial for the inconvenient truth that the Earth orbits the Sun
1636	Pierre de Fermat devises a three dimensional coordinate system but doesn't publish it
1637	René Descartes publishes his two-dimensional coordinate system
1637	Galileo Galilei conceives the idea of a pendulum clock but dies in 1642 before it could be built

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Year	Event
1656	Christiaan Huygens builds a pendulum clock
1665	(The Plague Year) Isaac Newton dreams up calculus, not published until 1735
1675	Leibniz develops his calculus and publishes the notation we use today
1752	Britain and its colonies adopt the Gregorian calendar by dropping 12 days from the Julian calendar
~1800	Form of 'Arabic' (actually European) numerals finally becomes stabilized
1805	Francis Beaufort establishes a wind scale based on the winds effect on canvas sails
1812	Napoleon spreads the metric system through Europe
1846	Thomas Robinson invents the four-cup anemometer
1884	Giuseppe Mercalli formalizes an earthquake scale (MM) based on observations and damage
1906	A major earthquake devastates San Francisco—recently rated as 7.9 M _W
1906	George Simpson publishes the 3/2 Power Law for the Beaufort wind scale
1926	Thomas Patterson invents the three-cup anemometer
1935	Charles Richter proposes an earthquake scale appropriate for California (M _L)
1946	The Beaufort wind scale is extended to B17 to include the winds in tropical cyclones
1954	Paul Niggli publishes <i>Rocks and Mineral Deposits</i>
1958	My friends and I try our hand at making absinthe
1971	Tetsuya Fujita and Allen Pearson, introduce a scale for rating the intensity of tornados in the United States
1972	Herbert Saffir and Robert Simpson developed a scale for alerting the U.S. public to the danger posed by hurricanes according to the intensity of their winds
1974	Terence Meaden proposes a tropical storm wind scale, TORRO—T0—T10 based on the 3/2 Power Law, with T0 = Beaufort Scale B8
1979	Seismologists Thomas C. Hanks and Hiroo Kanamori publish an earthquake scale based on the total amount of energy released: The Moment Magnitude Scale (M _W)

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Year	Event
1988	Cesare Emiliani publishes <i>The Scientific Companion</i> and predicts that doomsday will occur in 2023
1991	Cesare Emiliani publishes <i>Avogadro's number: a royal confusion</i> in the <i>Journal of Geological Education</i>
1992	Emiliani publishes <i>Planet Earth Cosmology, Geology, and the Evolution of Life and Environment</i> . He concludes that Mathematics must be the work of the Devil
1998	James Rodger Fleming publishes his book <i>Historical Perspectives on Climate Change</i>
2010	A Mw 7 earthquake hits Haiti causing the deaths of over 200,000 people
2010	A Mw 8.8 earthquake near Maule, Chile, results in 577 deaths
2011	A Mw 9 earthquake and subsequent tsunami devastates areas of eastern Japan

If you want to know more:

Adhikari, S. K., 1998. Babylonian Mathematics. *Indian Journal of History of Science*, v. 33/1, pp. 1–23.—A free copy of this fascinating article has been available on the Internet at http://www.new1.dli.ernet.in/data1/upload/insa/INSA_2/20005a5d_1.pdf

Fuller, R.B. & Applewhite, E.J., 1975. *Synergetics: Explorations in the Geometry of Thinking*. Macmillan, 876 pp.—A mind bender.

Fuller, R.B. & Applewhite, E.J., 1979. *Synergetics 2: Further Explorations in the Geometry of Thinking*. Macmillan, 592 pp.—For further bending of the mind.

Emiliani, C., 1992. *Planet Earth: Cosmology, Geology, and the Evolution of Life and Environment*. Cambridge University Press, 736 pp.—A great, stimulating introduction to our planet and its history.

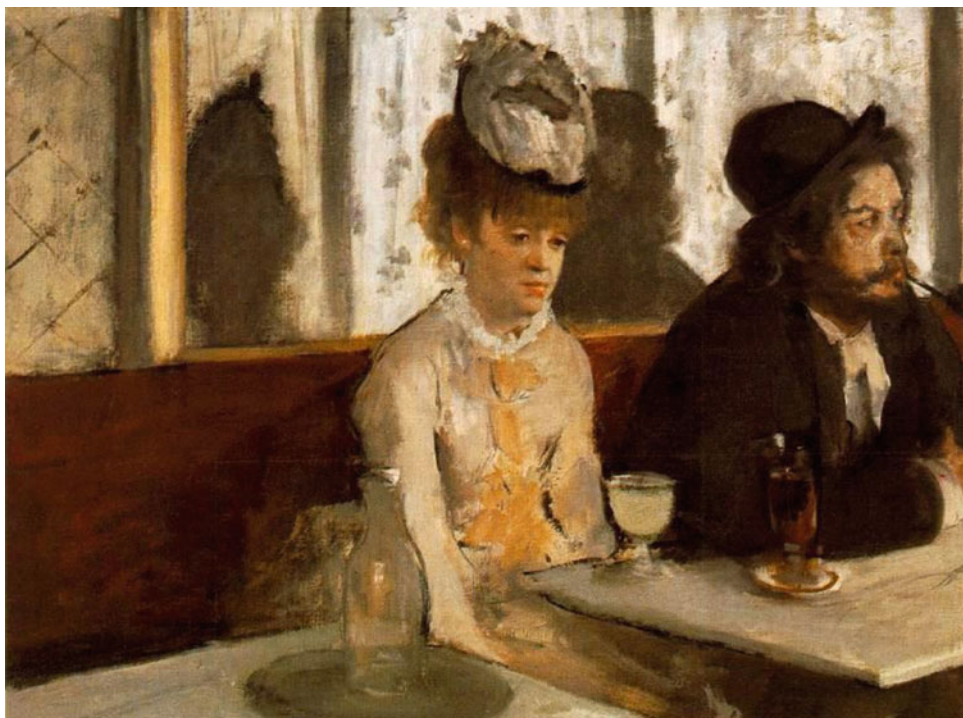
Emiliani, C., 1995. *The Scientific Companion: Exploring the Physical World with Facts, Figures, and Formulas*, 2nd edition. Wiley Popular Science, 268 p.—An overall introduction to science and the scientific method.

Joseph, G.G., 2011. *The Crest of the Peacock—Non-European Roots of Mathematics*, 3rd edition. Princeton University Press, 561 pp.—A voyage into the unknown for those who enjoy mathematics.

Music for contemplation of what you have read: J.S. Bach: The Brandenburg Concertos, any or all.

Libation: Absinthe, of course. I recommend Absinthe Ordinaire. It is named not because it is in any way ordinary, but because it uses the formula created by Dr. Joseph Ordinaire in rural France in 1789, just in time for the Revolution. It is supposed to turn you into a wild-eyed liberal. These have included Ernest Hemingway, James Joyce, Charles Baudelaire, Paul Verlaine, Arthur Rimbaud, Henri

Fig. 2.9 Edgar Degas (1834–1917). *L'Absinthe* (1876)



de Toulouse-Lautrec, Amadeo Modigliani, Pablo Picasso, Vincent van Gogh, Oscar Wilde, and Erik Satie (Fig. 2.9).

It tastes of licorice with a hint of wormwood. Tradition requires that it be poured very slowly into a glass over a cube of sugar resting on a slotted spoon.

The ban on Absinthe started in Switzerland in 1908 after an investigation sponsored by the Swiss Winegrowers Association. They had become concerned that Absinthe was replacing wine as an Aperitif, a pre-dinner drink. In 1905 a Swiss farmer, Jean Lanfray, had murdered his family and attempted to take his own life after drinking absinthe. The fact that he was an alcoholic and had consumed a purported nine bottles of wine earlier in the day was overlooked and the Winegrowers Association succeeded to getting a ban on Absinthe written into the Swiss Constitution. Most of Europe and the United States, but not Australia, followed suit.

Investigations into the purported hallucinogenic properties of Absinthe were conducted in the 1980s and since; none were found. The ban was lifted in the U.S. in 2007. The French Senate voted to repeal the prohibition in 2011.

Intermezzo II. Undergraduate Study—Three Universities and One Degree in 4 Years

I graduated from a private high school (St. Mark's School of Texas) in 1951 when I was 16 years old. I was the youngest member of my graduating class. There was never any question where I was going to college, our family had close ties to Southern Methodist University, and my father was a Trustee. However, when I applied to SMU there was some concern that I was too young to enter, but that problem got solved. I might even have received an award for financial aid because I had been Valedictorian of my high school graduating class, but that was ruled out by my father. As far as he was concerned, financial aid was for those who could not afford to attend otherwise. Anyway, I would be living at home, and so all we had to worry about was tuition and 'incidental expenses.'

I started off taking a pre-med curriculum; that was regarded as the most rigorous set of courses for a biology major. During my freshman year I joined the photography club, and here is where serendipity enters the scene. One of those in the club was an exchange student from Germany, Heinz Just. He was considered a junior at SMU, and had come from the University of Munich. He wanted to learn how to develop film and make prints, and I already knew all about this because my brother and I had transformed the hall closet in our house into a darkroom so small that only one person could fit in at a time. SMU had a fine darkroom available for the photography club. I taught Heinz not only how to develop film, but the tricks of how to

make prints even when the negative wasn't all that good. We would talk, and I learned that his family had lived in the Sudetenland, which before the war was a largely German-speaking part of Czechoslovakia. During the war he had been sent to Bavaria, far from anyplace that might be bombed. At the end of the war the German population was expelled from the Sudetenland. In the chaos at the end of the war, Heinz and his parents had to search for each other. I introduced him to my family, who were interested to discover that the people we had been fighting were, after all, humans too. I tried to find out what 'exchange student' really meant and found out that Senator Fulbright had set up a program, but it was only open to Americans for graduate study. Again serendipity steps in. When my father was a boy, the Hay's used to vacation in Arkansas, and they stayed at the Fulbright's rooming house, so dad and the Senator were childhood friends. My father figured that if Senator Fulbright thought these exchanges were a good thing, they must be. Heinz went back to Germany at the end of my freshman year.

In those days, if you were interested in what was happening in Europe and particularly the inside history of World War II, SMU was a very interesting place to be. Robert Storey, who had been Executive Trial Counsel for the United States at the Nuremberg Trial of major Axis War Criminals, was the Dean of the Law School. Hans Bernd Gisevius was also on the campus. He had been a surreptitious member of the German Resistance, and as Vice Consul in the Germany Embassy in Zurich had acted as intermediary between Allen Dulles and the Resistance in Germany. The Resistance was responsible for the July 20th, 1944 attempt to assassinate Hitler. There were interesting and insightful lectures from time to time.

During my sophomore year, I met another student from Germany, Peter Trawniki, through the German Department's club. Peter had been invited to come for a year by his uncle who lived in Dallas. The Trawniks lived in Gräfelfing, just outside Munich, a village untouched by the war. But he described one night in 1944 when there was a devastating air attack on Munich. The Trawniks climbed up onto the roof of their house to watch the city burn.

Halfway through my sophomore year the German Department at SMU announced an interesting opportunity. Wayne State University in Detroit intended to reopen their "Junior Year in Munich" program (hereafter JYM) which had been shut down in the 1930s. The first group of students would go for the 1953–54 academic year. Serendipity strikes again. That was the

year I would be a Junior, and I already had two friends in Munich. I asked my parents if I could apply. My mother was skeptical, but my father thought it was a great idea. We realized that living conditions would be very different from the peace and quiet of Dallas. And the cold war was heating up. There was always concern about whether it might turn into another war in Europe. Peter Trawnik convinced me that the most interesting way to travel to Europe was on a freighter. Before I left, I received some really good news. Heinz had managed to get me into the first student dormitory built for the University of Munich—a brand new building, with all the comforts of a dormitory in the US. Well, almost, anyway. It turned out we had warm water once a week.

I sailed from New York in June, 1953, on a freighter which took almost 2 weeks to reach Hamburg. There were five other passengers and no entertainment other than reading. We had meals with the Captain. Everything went well until we reached the North Sea and encountered huge waves. It was while I was at sea and ‘out of touch’ that the June 17th workers uprising in East Germany occurred. It was a huge event in the US, considered by many a prelude to war. Fifty years later I was to learn that our Junior Year in Munich was almost canceled because half of the students had withdrawn for fear they would get caught in a crisis. For me ignorance was bliss, and fortunately my family never expressed any concern.

Heinz had a friend in Hamburg, Horst, but I had been told that he worked all day. I was to go to his family’s home and would stay there for a couple of days. When the freighter docked, I took a cab to the address. It looked rather bleak, and I can still remember hauling my suitcase up the decrepit stairway in a building that still showed many of the scars of war. I knocked on the door and was greeted by Horst’s mother, who made me instantly feel at home. After unpacking I went out for a walk. Hamburg had been virtually destroyed in air raids, and many of the houses were simply shells. For someone who had never seen the destruction of war, it was a very sobering experience. That night we went to Planten un Blomen a huge park near the city center. There fountains and lights played to classical music provided by a symphony orchestra. I had never seen anything like it. Here in the midst of rebuilding from the destruction was a new unique art form—water, light and music. The next few days I wandered about the city fascinated by the modern buildings built (or rebuilt) of dark red bricks and at the ruins which still remained.

I took a train (changing successfully several times), to Neuburg an der Donau, where Heinz met me at the station and took me to his parent’s apartment. After a couple of days I went alone to Bayreuth for the Wagner festival. I had managed to get tickets before I left the US. It was the year that there were radical new stage settings by Wieland Wagner. Again I had never seen anything like it. The Festival Opera house in Bayreuth was built especially for Richard Wagner’s operas and had many special features. For one thing, you cannot see the orchestra pit; it is under the stage, and no light comes out from it. I had tickets for a complete performance of “*The Ring*”—four operas. The first “*Das Rheingold*” is performed without intermission and starts in late afternoon. You go in, take your seat, the lights go out, and it is pitch dark. The music begins in total darkness. The first part of *Rheingold* takes place in the Rhine River. In it, Rhine maidens are swimming about, singing. You only see these ladies appearing from time to time in the gloom toward the front of the auditorium. You can’t see where the stage is, but gradually the faint rippling of light coming through the water covers the whole front of the space. After the performance, I had dinner in an outdoor restaurant on top of the nearby hill. The next day’s performance was “*Die Walküre*.” It is in three acts, with an hour or more intermission between each, so you can go to one of the restaurants and have a meal spaced out over the evening. *Walküre* ends with Wotan putting Brünnhilde to sleep surrounded by a ring of magic fire. Those were the biggest, most impressive flames I have ever seen on a stage. I think it was done with a motion picture of flames projected onto a wall of steam. However it was done, it seemed unbelievably real. I was astonished at the originality of everything. The third opera, “*Siegfried*,” was performed the next day, again with long intermissions. The fourth day was a pause, for ‘light entertainment’ in the Festival Hall—Beethoven’s 9th Symphony conducted by Bruno Walter. And finally, on the fifth day the performance was, “*Die Götterdämmerung*,” the ‘Twilight of the Gods’ complete with the rainbow bridge leading to Valhalla. At this point I was seriously considering scrapping the idea of becoming a paleontologist and thinking that stage set design would be a lot more fun.

The next day Heinz arrived about noon with the Volkswagen beetle we had rented for our grand trans-alpine tour. That evening we saw *Tristan und Isolde*. It was when going to dinner between the second and third acts, that I had an unexpected encounter

with one of Hitler's more valuable deputies. Heinz was walking in front of me, and I was looking down at the path to the restaurant and thinking about what I had just seen, when I walked straight into an elderly gentleman, very nearly knocking him completely down. I caught him and helped him back up. Heinz had a shocked expression on his face. As the gentleman walked away with his friends, Heinz asked me "Do you know who that was?" I turns out I had bumped into Hjalmar Horace Greeley Schacht. Of course the name meant nothing to me. Heinz explained to me. Hjalmar Schacht had been Director of the Reichsbank under the Weimar Republic and continued in that position under Hitler. He was responsible for rebuilding the German economy and keeping it functioning during the war. He had been tried for war crimes at Nuremberg and found not guilty. It was concluded that he had just been doing what bankers do. If I had known who he was, I could have at least asked him how he got his name.

On Friday the 14th of August we drove to Nürnberg. Much was still in ruins, and there were large areas of the old town that were simply open spaces with rubble. But from what had been rebuilt it was already clear that the ancient center of this great medieval city was going to be reconstructed as close to its original form as possible. On Saturday we went swimming in the Main River and visited one of the Baroque palaces outside Bayreuth. In the evening we saw *Parzifal*. I've seen several performances since, but nothing quite as magical or mystical as that one in Bayreuth 1953. The Holy Grail was represented by a bowl, which began to glow and then gradually emitted intense brilliant light. I have no idea how that effect was achieved in those days.

The next day we were off on what was the greatest tour of Europe I have had. Following Tom Cranfill's advice I had obtained tickets to the Salzburg Festival. We went by way of Munich, my first chance to see the city I would be living in. At the end of the war the central part of Munich was more than 90 % destroyed and overall damage was over 60 %. That meant that 3 out of 5 buildings were either gone or in ruins. A lot of rebuilding had been done in the 9 years since the war, but there were still ruins everywhere. It seemed that the only buildings to survive the bombing were those Hitler had built: the two Nazi Party Headquarters buildings on Königsplatz (after the war one became the America House, the other became part of the Hochschule für Musik und Theater), the Gestapo Headquarters on Ludwigstrasse (then the US

Consulate), and the Haus der Kunst (originally the Haus der deutschen Kunst, for Nazi-approved art; after the war it was used to house the highlights of the fabulous Bavarian collections of art; the major galleries, the Pinakotheken, were all still in ruins). In contrast to some of the other cities which had been largely destroyed, the decision was made to rebuild Munich much as it had been before the war. I spent a sabbatical in Munich in 1988, and found that almost all physical traces of the war were gone. Interestingly, the students at the University then didn't seem to know that all of the streets lined with 18th and 19th century buildings and houses had been burned out and were ruins 40 years earlier.

We went for lunch at the Biergarten of the Löwenbräukeller on Stiglmaierplatz. It had been reconstructed just the way it had been before its destruction in a bombing raid in 1944. I had my first encounter with one of Munich's most famous specialties, Leberknödelsuppe (liver dumpling soup). A few hours later I was sick to my stomach and I blamed the soup. But we made it in good time to Salzburg and Heinz gave me the traditional remedy: a sugar cube soaked with several drops of Underberg bitters. It worked within a few hours, but I was still under the weather and decided to skip the performance of Handel's *Julius Cesar* that evening. It was many months before I tried Leberknödelsuppe again. Now I regard it as a delicacy, not to be missed on a visit to Munich.

The next day I had recovered and that evening saw the world premiere of a new opera, Gottfried von Einem's "*Der Prozess*" ("*The Trial*"). The opera is based on Franz Kafka's book. Josef K is arrested without being told why, tried for an unnamed crime, and convicted. It is a dark and surreal story, and very depressing. Von Einem's music is influenced by Stravinsky and Prokofiev, and was well suited to the theme. During the intermission I saw a small man standing alone looking at the audience. I walked over to him and asked how he liked the opera. He told me he would like to know what I thought of it. After some discussion we introduced ourselves. He was Gottfried von Einem. I liked *Der Prozess*, but it has not made its way into the repertoire of major opera houses. Little did I suspect that almost two decades later a close friend, Pavel Čepecký, would be caught up in a real trial in Prague, very much like that in Kafka's play.

The next day we drove through the spectacular lake and mountain scenery of the Salzkammergut. And in the evening saw a memorable performance of "*Don Giovanni*" at the Festival Hall. The circum-alpine tour

of the next month, through the Austrian Alps, northern Italy, southwestern France and Switzerland was literally the experience of a lifetime. In those days, you could stay in youth hostels and small hotels and eat in local restaurants for a pittance. On the advice of Tom Cranfill we discovered the 'other' Riviera, the one between Genoa and La Spezia which is still a gem. But perhaps the highlight of the trip for me was to Chamonix to see Mont Blanc and then on to Zermatt to see the Matterhorn. In 1953 there were none of the cableways that exist today; there were long and sometimes difficult hikes to see the sights.

Returning to Munich, I moved into the Red House, Studentenheim am Biederstein, where Heinz and I shared a tiny room. A few years ago Heinz, after having visited an exhibition on cubist art in Ferrara, reminded me that I covered the walls with prints of paintings by Braque. I think I was more fortunate that the other members of our American group in that I instantly had about 30 friends, all with interesting stories to tell. With one exception all had been too young to serve in the military. The exception was our wise Papa Wagner, in his twenties. He had been a fighter pilot in the Luftwaffe, and although he was less than a decade older than the rest of us, he was our local father figure.

Our Junior Year group started the semester early, in September, with special courses in German Language and European History. For the University of Munich (its real name is Ludwig-Maximilian Universität, better known simply as LMU) the semester began in October. We were able to enroll in regular courses in the University. The German students do not take exams until they are ready to finish their studies after 4 years at the University. If we wanted to attend University lectures and get JYM credit for a course, JYM provided tutors and we would get special exams arranged for us. A peculiarity of the University system in Germany (and much of Europe), is that the students keep their own records. The University issued each student a 'Studienbuch.' You would write in it what lectures you were attending. After one of the lectures, sometime during the semester, you would go up to the Professor and get his signature in the Studienbuch. Of course, that meant that in reality you only needed to attend one lecture (or give your Studienbuch to someone else to get the required signature). A complete honor system. Basically, you could learn the material any way you wanted. What counted was how well you did on the end of your studies when you took

all the exams, usually over about a 2 week period. For the typical German student this meant that the first year was spent in confusion trying to figure out what you were doing. Year 2 was pure fun, having parties and general good times. Year 3 was a time for moderate panic, and year 4 was spent in total panic preparing for the exams. You also need to realize that German Universities (and most in Europe) do not have tuition. Higher education is free to those who are qualified. You pay a small fee and get the right to get a pass on public transportation, greatly reduced prices for tickets to concerts, opera, plays, museums, etc. The last time I was in Munich, the University was trying to figure out what to do about the perpetual 'students' who never seemed to finish but took advantage of these amenities, an estimated 20,000 out of 80,000 enrolled students.

My friends at the Studentenheim am Biederstein advised me that there were certain lectures you just had to have in your Studienbuch. I was able to sign up for them without asking for credit from the JYM. One absolute must was Advanced Sanskrit; no one ever seemed to take Introductory Sanskrit or to attend more than the one lecture required to get the Prof's signature. Another absolute must was to attend at least one of Professor Theodor Dombart's lectures on Egyptology. Dombart looked the part of a proper Egyptologist of the time. In his sixties, he had a triangular beard that extended down almost to his waist. German sentences usually have the verb at the end. In lecturing Dombart was able to devise very long and complex sentences that could go on for a minute or more, and then forget the verb at the end, leaving you up in the air as to what it was about. Or sometimes he would remember the verb and follow it with a 'nicht' which negated everything he had just said. And then there were the lectures on Art History by Hans Sedlmayer, open to all students in the University. The audiences always completely filled the AudiMax, the Auditorium Maximum, the largest lecture hall in the University, with students sitting on all the steps as well. The lectures were great, but you could tell when the end was coming because Professor Sedlmayer would start putting on his coat and shawl while still lecturing and give a final "Danke schön für Ihre Aufmerksamkeit" (Thank you for your attention) as he put on his hat and headed out the door.

The main building of the University on the Ludwigstrasse had opened, but some of the roof was missing, and parts of the building were still in ruins.

When winter came it was cold, and most of the classrooms were not heated. I wore a heavy winter coat and gloves—not the easiest gear for taking notes.

I called back to the US a few times to talk to my parents. It wasn't easy. Germany had been allowed to keep a single transatlantic cable at the end of the war. To place a call to America you went to the post-telephone office and made an appointment for the call, usually 10 days or more in advance. When the day came you would wait until you were called and assigned to a booth. Then you would wait in the booth until the connection had been made, usually a few minutes. Then you had maybe 5 min to exchange pleasantries before you were cut off so the next person could make his call.

Nevertheless, that year in Munich was the highlight of my life. I went to concerts, operas or plays an average of 4 days each week. Tickets for students always seemed to be available and were incredibly cheap. There was only one large concert hall, the Herkulessaal in the Residenz, but already two Opera houses. Munich already had four symphony orchestras (it now has five) and you could hear anything from music by Orlando di Lasso (16th century) to the concert series Musica Viva, which never performed anything older than 10 years. Serious opera was in the Prinzregententheater, a near duplicate of the Festival House in Bayreuth, and also built for Wagner's Operas. One of the highlights was Carl Orff's "*Carmina Burana*." I sat in the last row. Orff himself was in the box immediately behind me. Whether you know it or not, you have heard at least part of *Carmina Burana*; the themes have been used in so many films and TV shows. It is sometimes called the first piece of rock music. It consists of secular songs in vulgate Latin sung by monks. In that 1954 staging the 50 or so monks making the chorus were dressed in blue and red robes and were sitting around a huge round table that occupied most of the stage. Soloists would appear on the table. I've seen a number of performances since, none with such grand staging. Another memorable performance was a Stravinsky ballet with stage sets designed by Paul Klee.

The Theater am Gärtnerplatz, which burned out in one of the air-raids in July, 1944, had been rebuilt and was in operation every day. It did light opera, operettas and musicals. Again, I was fascinated by the staging which sometimes involved movies projected onto the background.

Our Junior Year program gave us the regular German University vacation periods off, three weeks over

Christmas/New Year and two months between the winter and summer semesters. So I was able to spend several weeks in Vienna, Rome, and Paris. In Rome I attended a concert in the Palazzo Farnese. Much later I realized that the Palazzo Farnese was the setting for Act 2 of *Tosca*, where she murders Scarpia. A few years ago a friend going to *Tosca* as his first opera once asked me "what is it about?" I had to respond "Well, false imprisonment, torture, rape, murder, betrayal and suicide—the usual things."

Fasching is Munich's version of Mardi Gras, only instead of 1 day it lasts at least 2 months, from just after New Year until the beginning of Lent. It is the darkest coldest part of the winter, and to make up for it there are parties. Big Parties, costume parties called Balls. Almost all were open to the public for the modest price of a ticket. Attendance was usually between one and five thousand revelers. I believe their real purpose is to make sure you have something to repent during Lent. On weekends there might be as many as 30 costume balls each night. The festivities would start about 9 PM, but most students didn't arrive until much later, and the balls would end at dawn. The early morning streetcars would be full of people in every sort of outlandish costume. It was common to go with your girlfriend but to leave with someone else's. The art was removed from the Haus der Kunst, and the building was transformed into a painted cave with fantastic lighting. But for me the best parties were in the underground air-raid bunkers of the Regina Hotel underneath Lenbach Platz and the surrounding area. The bunkers, ordinarily sealed but opened for Fasching, were a labyrinth. There were many little rooms and three large ones where there would be orchestras and dance floors. Once into the maze you could have the devil of a time finding your way back out again. Most people wore masks or had their faces painted so well you couldn't even recognize friends. You would soon lose those you had come with and be having a good time with total strangers without ever finding out who they were. You might even wind up going together to a breakfast of Weisswurst and beer in one of the early-opening restaurants. In retrospect, it was remarkably innocent fun and good therapy for those who had experienced the war first hand. Now it is much more formal, much less exciting and fun: today many of the Munich students go to Venice for Carnival instead.

Although that year in Munich was the most exciting time of my life, I am amazed when I look back at the pictures I took that it was still a city largely in ruins.

And this was 8 years after the war had ended. Although I never participated directly in war, the experience of living in a bombed-out city left me with a real contempt for those who regard it as a reasonable way of solving problems.

My last year at SMU was spent partly planning on going to graduate school and more intensively planning on how to get back to Europe, maybe the next time to somewhere that had not been so affected by war.

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