Chapter 11

Milliworld

0.001 (1.0 x 10^{-3}) m

11.1 Milliworld Length

1 – 1000 millimeters (mm) 1 x 10^{-3}

The linear distance covered by Milliworld length is from 1 millimeter to 1000 millimeters (1 meter). Milliworld encompasses dimensions which describe many of the objects in the world around us. A dime is 1.5 millimeters thick. The width of a human finger is approximately 20 millimeters. The width of a human hand is about 100 mm. The diameter of a compact disc is 120 millimeters. The length of a North American male foot is about 263 millimeters, which is about 14% smaller than the US pre-metric unit of the same name.

In 1969, two Apollo 11 astronauts placed a reflector array on the surface of the Moon in the Sea of Tranquillity. Earth-based researchers have been using it to reflect laser light from the Earth to the Moon and back ever since. By measuring the round-trip time taken by this light, it has been determined the Moon is receding from the Earth at a rate of about 38 millimeters per year. This distance is about the diameter of a ping pong (table tennis) ball. The 38 mm value is an average of continuous measurement over the years. The value is consistently measured, except on nights

Millimeter Scale Examples

Object	Length
Thickness of a Dime	1.5 mm
Big Bang Spectral Radiance Wavelength	1.871 mm
Small Spherical Raindrop Diameter	2 mm
Width of Adult Human Finger	20 mm
Distance The Moon Recedes From the Earth in 1 Year	38 mm
Diameter of a Ping Pong Ball	40 mm
Edge of Rubik's Cube	57 mm
Diameter of a Baseball	75 mm
Width of Adult Human Hand	100 mm
Compact Disc Diameter	120 mm
Hydrogen Microwave Emission Wavelength	211 mm
US Male Foot	263 mm
Current Yearly Erosion Rate of Niagara Falls	300 mm
Coffee Table Height	450 mm
Desk Height	750 mm
Historical Yearly Erosion Rate of Niagara Falls	910 mm
Length of Human Stride	1000 mm

Table 11.1: Millimeter Example Lengths

when the moon is full. The signal then becomes faint, about 1% of the expected reflection, or essentially disappears entirely. The "full moon curse" of the Apollo 11 reflector array is consistent with the full moon month, after month.[1]

When three or more planets are in a roughly straight-line configuration, this is called *syzygy*. With every full moon, and new moon, the Earth, Moon, and Sun are in alignment. When a full moon occurs, the Sun, Earth and Moon are in a straight line. A new moon happens when the Sun, Moon and Earth are in syzygy.

Speculation began about why the "full moon curse" was manifesting itself. The leading contender was heat. The prisms of the retroreflector are inset into cylinders. Because of this geometry, the Sun only maximally illuminates the retroreflector elements when it shines straight into the tubes. The array is pointed toward Earth, so the only time this happens is on full moon nights.

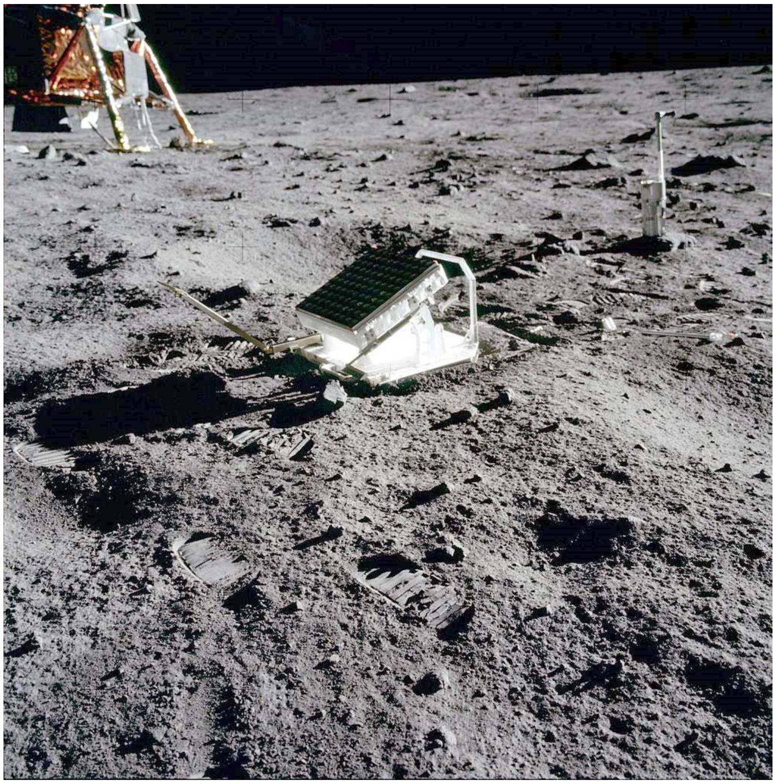

Figure 11.1: Apollo 11 Lunar Laser Ranging Experiment – NASA

The surface dust is thought to heat up, whereas the lower part of the structure is at a lower temperature. This alters the geometry of the reflector elements enough to considerably degrade their performance, and in turn the entire retroreflector array.

This speculation produced a testable hypothesis. If one could block the Sun during a full moon, then the reflector's efficiency should remain stable. This happens naturally during a lunar eclipse. On the night of July 21, 2010* scientists at UC San Diego,

*2010-07-21 per ISO 8601 which everyone reading this work should use as a date abbreviation.

led by Tom Murphy, had satisfactory observing conditions during a lunar eclipse. The researchers were able to aim lasers at the three Apollo reflector arrays, and a fourth mounted on a Soviet rover, for five and a half hours. They took data from these arrays as the edge of the Earth's shadow passed over each of them in-turn, and as the opposite edge re-illuminated them one-by-one.

As predicted, when the reflectors were in the shadow, their performance increased by ten-fold, to the same levels seen on typical nights, removing "the curse of the full moon," with a scientific explanation.

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A human stride is often used to approximate a meter (1000 mm) when a measuring device is unavailable.

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Raindrops range from 100 micrometers to 9 millimeters in mean diameter. The traditional artistic portrayal of a falling raindrop, with a rounded bottom and pointed top, does not match reality. When a raindrop is less than two millimeters in diameter, it is spherical. When a raindrop is larger than two millimeters, air resistance begins to flatten its bottom. The raindrop then becomes shaped like a hamburger bun. Raindrops begin to look more like parachutes as they approach diameters of 5 mm. Beyond five millimeters, a drop becomes unstable and bifurcates into two drops.

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Electromagnetic waves with wavelengths measured in millimeters, are called, appropriately enough, millimeter waves. They are defined as waves which range from 1-10 millimeters in wavelength. This corresponds to a frequency range of 30 to 300 Gigahertz.

In 1964, researchers Arno Penzias (1933 –) and Robert Wilson (1936 –) were employed at Bell Labs. They were working with the most sensitive microwave antenna/receiver system yet developed. The pair unexpectedly received noise which had no conventional explanation.

The sectoral horn antenna they were using was rotated, and the unexpected noise remained at a consistent level. This made the two researchers suspicious the source of the noise might be of terrestrial origin. The inside of the antenna had become a residence for pigeons, and their droppings were considered a potential contributor to the noise. After removing the excrement (and the pigeons) the noise remained.

The unexpected noise was finally recognized as the microwave afterglow of the Big Bang, and lead to the 1978 Nobel Prize for Physics. The noise produced by the afterglow of the Big Bang is a mixture of frequencies. The peak value of this spectral radiance, in terms of frequencies, is 160.2 GHz, which equates to a wavelength of 1.871 mm.

Dutch astronomer Hendrik C. van de Hulst (1918-2000) mathematically predicted in 1944, that interstellar hydrogen should have a transition which would radiate an electromagnetic wave with a 211 mm wavelength. This transition would occur very, very, rarely, at the astonishingly small frequency of 2.9 femtohertz.† This means very few hydrogen atoms ever emit this electromagnetic radiation, but the large number of hydrogen atoms found in interstellar space, assures enough of them will radiate to become detectable.

These 211 millimeter (211.061 140 541 3 mm) wavelength, hydrogen-generated microwaves, (1.420 405 8 GHz) were discovered in 1951. They produce a gentle background illumination. When these microwaves were mapped in 1952, they revealed the spiral structure of the Milky Way Galaxy for the first time.

Between the interstellar hydrogen frequency (H), and the spectral line of strongest radiating hydroxl radical (OH) is a range of frequencies which are considered "quiet" by radio astronomers. This spectrum is proverbially dubbed "The Water Hole," as the combination of the ends is HOH or H_2O. The range of wavelengths which bookend this electromagnetic "channel," are from 180 mm to 211 mm approximately. This is the range of frequencies which

†About every 345 Teraseconds, or 11 000 000 years.

have been of great interest to researchers undertaking the Search for Extra Terrestrial Intelligence (SETI), and where they focus their attention.

Figure 11.2: View of Niagara Falls in 1969 when water was diverted to the Canadian side – Wikimedia Commons/Creative Commons

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About 10 900 years ago, Niagara Falls was about 10.9 Km north of its present location. The falls erodes its edge at a historical rate of 910 mm per year, currently its erosion rate is about 300 mm per year. Given these rates, in around 50 000 years, the falls will erode the final 32 Km to Lake Erie, and vanish.

The commercial tourist value of Niagara Falls was of concern in the 1960s. There were worries that rock, which had eroded from the top of the American Falls, might begin to turn this natural wonder into nothing but a mammoth rapids. The pile of rock below the falls is called talus. There was 200 000 cubic meters of talus below the falls in 1969. Was it feasible to remove it to make the American side of the falls more aesthetically pleasing? The pile of talus was almost half the height of the falls in some locations.

In June of 1969, the American falls were shut-off until December to find out (see Figure 11.2). To achieve this diversion of the river, a 200 meter cofferdam was erected upstream using 25 000 Megagrams of material, and a dry area behind the falls was created. Millions of coins, and even a few human bodies were found in the dry rock bed. The Army Corps of Engineers came to the conclusion that the talus was probably reinforcing the face of the falls, and the talus was left intact. The engineers used the opportunity to stabilize the rock face using cables, bolts and anchors. They also installed electronic rockslide sensors. It was concluded that it seemed "wrong to make the Falls static and unnatural, like an artificial waterfall in a garden or a park."

11.2 Milliworld Area

1 – 1 000 000 square millimeters (mm) 1 x 10^{-6} m^2

The range of area in Milliworld is from 1 square millimeter to 1 000 000 square millimeters, which is equivalent to 1 square meter. The square millimeter is very small, about the area of a large flake of ground black peppercorn. In other words, a large flake of black pepper from your pepper shaker has an area of about 1 mm^2. The head of a pin is 2 mm^2. The size of the optic nerve that connects to your retina is about 3 square millimeters. Your retina covers an area of around 1000 mm^2

The hole in US three-ring binder paper has a diameter of about 8 mm, and occupies an area of about 50 square millimeters.

A dime has a diameter of 17.9 mm and a corresponding surface area of approximately 250 mm^2. A half–dollar covers an area of about 736 mm^2. The area of a dollar bill is 10 339 square millimeters. It would take just over 41 dimes to cover this area. A single sheet of square toilet tissue is approximately 100 mm x 100 mm or 10 000 mm^2. An A4 sheet of paper[‡] is 210 mm x 297 mm, for a surface area of 62 370 mm^2.

[‡]A4 is similar in size to 8.5" x 11"

Surface Areas in Milliworld

Object	Surface Area
Ground Pepper	1 mm^2
Head of a Pin	2 mm^2
Optic Nerve Area in Humans	3 mm^2
Hole in Notebook Paper	50 mm^2
Dime	250 mm^2
Half Dollar	736 mm^2
Retina Area of Human Eye	1 000 mm^2
Sheet of Toilet Paper	10 000 mm^2
Dollar Bill	10 339 mm^2
A4 Paper	62 500 mm^2
Carl Friedrich Gauss's Brain	219 588 mm^2
Mill Ends Park	292 000 mm^2
Large Manhole Cover	727 000 mm^2
1 Square Meter	1 000 000 mm^2

Table 11.2: Surface Areas in Milliworld

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Mathematician Carl Friedrich Gauss (1777-1855) is reported to have had a brain with a cerebral surface area of 219 588 square millimeters. A non-SI unit of magnetic flux is named the gauss after this brilliant mathematician, who contributed considerably to our understanding of magnetism.

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The smallest park in the world[§], a circle with a diameter of 610 mm, is Mill Ends Park in Portland, Oregon. It covers an area of 292 000 square millimeters (around one-third of a square meter). This park is close to the size of a small manhole cover (607 mm). A large manhole cover has a diameter of 962 mm, and covers an area of about 727 000 square millimeters, which approaches 1 square meter of area.

[§]The park was granted recognition as the world's smallest park in 1971 by the *Guinness Book of World Records*

Figure 11.3: Mill Ends Park in 2007 (Wikimedia Commons)

According to legend, the site was originally allocated for a light pole. Weeds grew and no light pole was erected. A local newspaper columnist evicted the weeds and planted flowers. On St. Patricks day of 1948, the "park" was designated as "the only leprechaun colony west of Ireland." Mill Ends was designated an official city park in 1976. It has hosted a swimming pool for butterflies, a tiny Ferris wheel (delivered using a full sized crane) and other novelties.

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The area of A-series metric paper is presented in Table 11.3. The paper's area in square millimeters is approximately halved for each increment of the number next to A. That is, A1 is half of A0, A2 is half of A1, and so on. A-series paper areas, in square millimeters, span most of the domain of Milliworld area. The most commonly used paper size in everyday life is A4. It is similar in extent to letter-size paper in the US. A10 metric paper size is used for Australian postage stamps, an example of which is shown in Figure 11.4.

Surface Areas of A Series Paper

Paper Size	Dimensions	Surface Area
A0	841 mm x 1149 mm	999 949 mm^2
A1	594 mm x 841 mm	499 554 mm^2
A2	420 mm x 594 mm	249 480 mm^2
A3	297 mm x 420 mm	124 740 mm^2
A4	210 mm x 297 mm	62 370 mm^2
A5	148 mm x 210 mm	31 080 mm^2
A6	105 mm x 148 mm	15 540 mm^2
A7	74 mm x 105 mm	7 770 mm^2
A8	52 mm x 74 mm	3 840 mm^2
A9	37 mm x 52 mm	1 924 mm^2
A10	26 mm x 37 mm	962 mm^2

Table 11.3: Areas in Milliworld

Figure 11.4: Australian A10 Postage Stamp (26 mm x 37 mm)

11.3 Milliworld Volume

1 – 1000 milliliters (mL) 1 x 10^{-3} L

When a liter is divided by one thousand, we obtain a milliliter. A milliliter has the same volume as a cube with 10 millimeter sides, and contains 1000 cubic millimeters. When this volume is filled with water, it has a mass of one gram. Recall a cube with 100 mm sides is a liter, and when filled with water, masses 1000 grams, or one Kilogram.

The liter is almost exclusively used when reducing prefixes are applied to volume. On rare occasion in everyday life, one

Milliliter Volume Objects

Example	Volume
1000 mm^3	1 mL
Standard (16 mm) Die	4 mL
Volume of the International Prototype Kilogram	47.2 mL
Stick of Butter	130 mL
Rubik's Cube	185 mL
US Standard Soda Can	355 mL
US "Fifth" of Liquor	750 mL
1 000 000 mm^3	1000 mL

Table 11.4

may encounter a cubic millimeter (mm^3). There are about 60 cubic millimeters in a drop of water. The medical profession often uses cubic millimeters. White blood cell count is the number of white blood cells in a cubic millimeter of blood. It ranges from around 4300 to 10 800 cells/mm^3. One can get an idea how much higher the proportion of red blood cells in blood is, compared with white blood cells, as they have cell counts of 4 200 000 to 5 900 000 cells/mm^3 A cubic millimeter of volume is equal to a microliter (μL) so the blood counts could also be written as the number of cells per microliter.

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The volume of a single standard die (16 mm cube) from a pair of gaming dice is approximately 4 milliliters. This is the same volume as each of the 26 "virtual sub-cubes" making up a Rubik's Cube. Much of the interior volume of a Rubik's Cube is taken up with its operating mechanism.

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The volume of the International Prototype Kilogram (IPK) platinum-iridium cylinder is 47.2 milliliters. This volume is just slightly larger than that of a US single shot glass, which in Utah has a volume of 44 mL, as that is the only state to have instituted a standard for a single shot.

The volume of water used to originally define the Kilogram is one liter (1000 mL). The 952.8 mL difference between the original definition of the Kilogram using water, and that of the IPK, illustrates the high density of the platinum-iridium alloy used to manufacture the Kilogram artifact.

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A stick of butter in the United States has a volume of 130 mL.

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The Rubik's Cube was invented by Hungarian Erno Rubik (1944 –) in 1974. The standard cube has 57 mm long edges, with an enclosed volume of 185 milliliters. The number of permutations of a Rubik's cube is: 43 252 003 274 489 856 000, or about 43 Exa-positions.

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A standard can of soda (from a traditional six-pack) holds 355 mL of liquid. A "fifth" of whiskey is 750 mL.[¶]

11.4 Milliworld Mass

1 – 1000 milligrams (mg) 1 x 10^{-3} g

A honeybee's brain weighs about one milligram, and contains fewer than a million nerve cells. It is about the size of a single sesame seed, approximately a cubic millimeter.

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A spherical raindrop, with a mean diameter of 2 millimeters, has a mass of about 5 milligrams. A drop of water, which slowly oozes from a small aperture, and then falls to the ground, has a mass of approximately 60 milligrams. A sphere of water with a 10 mm diameter has a mass of 524 milligrams. A 1000 milligram (1 gram) sphere of water has a diameter of 12.41 millimeters.

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[¶]The US fifth was equal to 1/5 of a US gallon, which is equal to 4/5 of a quart, which is also equal to 25 3/5 fluid ounces, which is 757 mL. In the only US government guided metrication in the 1970s, it was defined as 750 mL

Milligram Mass Objects

Example	Mass
Honeybee Brain	1 mg
Snowflake	3 mg
Raindrop (2 mm diameter)	5 mg
Drop of Water	60 mg
Aspirin (baby strength)	81 mg
Aspirin (full strength)	325 mg
Bee Hummingbird Egg	500 mg
Sphere of Water (10 mm diameter)	524 mg
Sphere of Water (12.41 mm diameter)	1000 mg

Table 11.5: Items with Milligram Mass

The use of milligrams is common for medication. Aspirin tablets come in 81 milligram low dose tablets, and 325 milligram versions in the US.[‖]

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A bee hummingbird egg is about 500 milligrams and smaller than a pea. See Figure 11.5

[‖]These values are metric values based on pre-metric dosages. A 1.25 grain US aspirin is 81 milligrams, and a five grain tablet is 324 micrograms.

Figure 11.5: Bee Hummingbird Eggs

References

[1] University of California - San Diego. "Apollo reflectors performance: Source of 'full moon curse' revealed by eclipse." *ScienceDaily*, 11 February 2014. www.sciencedaily.com/releases/2014/02/140211121831.htm