Lesson 102:

THE METRIC SYSTEM AND MEASUREMENT

102

A review of the metric system and an introduction to proper scientific measurements and calculations.

Fundamental Questions

Attempting to give thorough and reasonable answers to the following questions will help you gauge your level of understanding this lesson. Students that can confidently answer these questions have mastered the concepts of this lesson.

1. Which unit of measurement is the best one for measuring something?
2. Which is larger, a kilometer or kilogram?
3. Why is the metric system better than the American system of measurement?
4. Why is mega-mile a strange unit of measurement?
5. How can we calculate the volume of space that Earth takes up?
6. Would kids understand fractions better if the United States switched to the metric system?
7. What things would have to change in the United States if we switched to the metric system?
8. When is scientific notation better to use for writing numbers?

Lesson Objectives

At the end of this lesson, students should have mastered the objectives listed below.

1. Students can read and write numbers in scientific notation.
2. Honors/Intensive students can properly enter scientific notation into a calculator so that answers do not become corrupted.
3. Honors/Intensive students can add, subtract, divide, and multiply numbers written in scientific notation.
4. Students construct their own ruler that uses a new measuring unit and can convert their new unit to inches and centimeters.
5. Students can use metric prefixes correctly to describe metric units that are larger/smaller than standard metric units.
6. Students understand how metric units relate to English (American) units.
7. Students can convert basic measurements in the metric system.
8. Students can match each unit to each type of measurement (e.g. mass is measured in grams)
9. Students can estimate metric measurements for commonly-used objects.
10. Honors and intensive students can convert imperial units into metric units and vice versa.
11. Students should know that 1 mL of pure water has a mass of 1 gram and 1 mL of ice has a mass of 0.92 grams.
12. Students understand how to take accurate and precise measurements.
13. Honors/Intensive students can apply the rules of significant figures to their calculations.

Important Terms

The following terms are some of the vocabulary that students should be familiar with in order to fully master this lesson.

1. scientific notation
2. googolplex
3. Metric System
4. length
5. mass
6. volume
7. temperature
8. weight
9. density
10. SI units
11. Metric prefixes
12. unit of uncertainty
13. conversion factor
14. precision
15. accuracy
16. exponent
17. significant figures
18. Crazy Fifi
19. absolute zero

Assessment Questions

The following are examples of questions that students should be able to answer. These or similar questions are likely to appear on the exam.

1. Measure the length of your pen and record the length in centimeters.
2. * What is a googolplex?
3. Write 186.9 in scientific notation.
4. Write 0.00589 in scientific notation.
5. * Divide 8.9x104 by 3.442x10-34 and write the answer in scientific notation.
6. * Add 8.669x103 and 8.82x104 and write the answer in scientific notation.
7. * Subtract 6.76x102 from 5.2x1045 and write the answer in scientific notation.
8. * Multiply 9.99x1054 by 5.4x1023 and write the answer in scientific notation.
9. What unit should the mass of a car be measured in?
10. What unit should the length of your fingers be measured in?
11. * How many liters of water can fit inside a 5-gallon bucket?

12. * How many meters is a mile?
13. * What is the density of water in pounds/gallon?
14. How many meters are in 50 kilometers?
15. How many grams are in a dekagram?
16. What is the SI unit for temperature?
17. What is the name used for 1,000,000 grams?
18. What is the name used for 1/10th of a second?
19. What is the name used for 1/1,000,000th of a meter?
20. What is the name used for 1/100th of a liter?
21. What is the name used for 100 grams?
22. What is the name used for 1000 meters?
23. What is the name used for 1/1000th of a liter?
24. What is the name used for 1/1000th of a gram?
25. What is the difference between accuracy and precision?
26. * How many significant figures are in the number 0.005098?
27. * How many significant figures should you have in your answer after multiplying 3.4 times 45.8932?
28. * Use the Crazy Fifi conversion method to convert 289.254 hectoseconds into seconds.
29. * Use the Crazy Fifi conversion method to convert 8456.934 kilograms into tons.
30. * Use the Crazy Fifi conversion method to convert 1.078 liters of pure water into grams.
31. * Use the Crazy Fifi conversion method to convert 9.78x1023 meters into parsecs.
32. * Use the Crazy Fifi conversion method to convert 14 miles into dekameters.
33. * Use the Crazy Fifi conversion method to convert 14 miles into dekameters.

Related Web Sites

The following are some web sites that are related to this lesson. You are encouraged to check out these sites to obtain additional information.

1. http://en.wikipedia.org/wiki/Metric_system
2. http://www.visionlearning.com/library/module_viewer.php?mid=47
3. http://www.sciencemadesimple.com/metric_system.html
4. http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWabbr.html
5. http://metricconversioncharts.org/
6. http://www.metric-conversions.org/
7. http://en.wikipedia.org/wiki/Scientific_notation
8. http://www.purplemath.com/modules/exponent3.htm
9. http://www.chem.tamu.edu/class/fyp/mathrev/mr-scnot.html
10. http://www.mathsisfun.com/numbers/scientific-notation.html
11. http://www.chem.sc.edu/faculty/morgan/resources/sigfigs/index.html
12. http://tournas.rice.edu/website/documents/SignificantFigureRules1.pdf
13. http://www.sciencegeek.net/APchemistry/APtaters/sigfigs.htm

Related Book Pages

The following are the pages from your book that correspond to this lesson.

Comprehensive E.S. Book	Intensive/Honors E.S. Book	Meteorology/GIS Book
pp. 736-741	pp. 14-16 and 909	N/A

Massachusetts Standards

The following are the Massachusetts Framework Standards that correspond to this lesson.

Earth Science Learning Standard(s) N/A

What's Next?

Notes

I. THE METRIC SYSTEM

A. Metric System - standardized system of measurement used worldwide

B. Common Measurements

1. mass – amount of matter (stuff) in an object
2. length – distance from one end point to another
3. volume – amount of *space* an object takes up
4. temperature – amount of *heat* that an object emits
   - All objects that have mass emit heat
   - The coldest possible temperature is -273.15°C, also known as **Absolute Zero** because it is 0°K on Kelvin Scale
5. weight - measure of the gravitational attraction between two objects that have mass

   In absence of gravity, an object does not weigh anything, but it does have mass.
6. density - mass per unit volume of a substance (D = m/V)
   a. Example of a high density substance: lead
   b. Example of a low density substance: oil

C. The most commonly used metric units are called *SI units*.

1. SI units are grams (mass), meters (length), liters (volume), Newtons (weight), degrees Celsius (temperature), and seconds (time).
2. "SI" stands for *International System of Measurement*.

D. Metric Prefixes

1. Metric prefixes are used to denote larger or smaller multiples of SI units.

Metric Prefix	Sci. Not.	Meaning
tera-	10^{12}	1,000,000,000,000 times larger
giga-	10^{9}	1,000,000,000 times larger
mega-	10^{6}	1,000,000 times larger
kilo-	10^{3}	1000 times larger
hecto-	10^{2}	100 times larger
deka-	10^{1}	10 times larger
deci-	10^{-1}	1/10th smaller
centi-	10^{-2}	1/100th smaller
milli-	10^{-3}	1/1000th smaller
micro-	10^{-6}	1/1,000,000th smaller
nano-	10^{-9}	1/1,000,000,000 smaller
pico-	10^{-12}	1/1,000,000,000,000 smaller

2. So a *centi*meter is 1/100th of a meter. In other words, there are 100 centimeters in a meter.

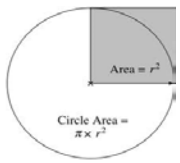
II. Scientific Notation

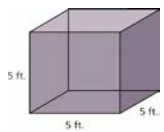
A. Scientists use scientific notation to denote very large or very small numbers

B. Numbers are written in exponential form

1. For example, 1,000,000 is written as 10^6
2. For example, 1/1000th is written as 10^{-3}
3. For example, 127 is written as 1.27×10^2

Scientific Notation	Distance	Mass	Volume	Force	Temperature	Time
10^{12}		teragram	teraliter			
10^{9}	gigameter			gigaNewton		gigasecond
10^{6}		megagram	megaliter		megadegrees Celsius	megasecond
10^{3}						kilosecond
10^{2}		hectogram		hectoNewton	hectodegrees Celsius	hectosecond
10^{1}	dekameter		dekaliter	dekaNewton	dekadegrees Celsius	
10^{0}	**meter**			**Newton**		**second**
10^{-1}		decigram	deciliter	deciNewton	decidegrees Celsius	
10^{-2}	centimeter	centigram				
10^{-3}					millidegrees Celsius	
10^{-6}			microliter	microNewton	microdegrees Celsius	
10^{-9}	nanometer			nanoNewton		nanosecond
10^{-12}			picoliter		microdegrees Celsius	picosecond





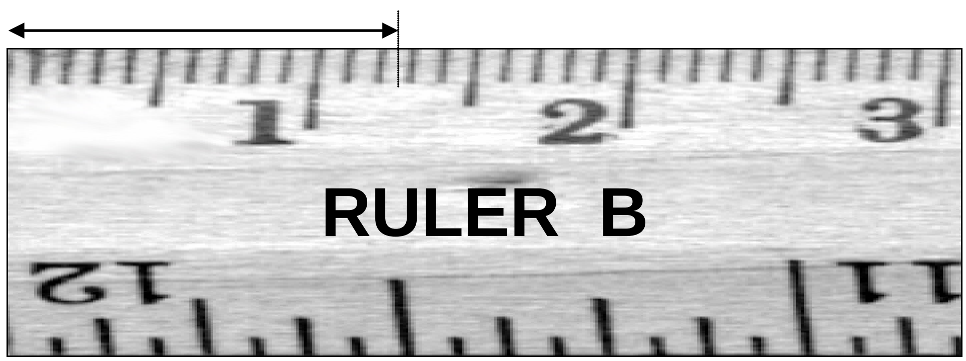



	Length	Area	Volume	Mass	Density	Weight	Time	Velocity	Temperature
Definition	"The distance between two points"	"The extent of a surface or plane"	"The amount of space an object takes up"	"The amount of matter (or stuff) in an object"	"The mass of an object per unit of its volume"	"The force that gravity exerts on an object"	"The measured duration of an event"	"The rate of change in position of an object"	"The amount of heat in an object"
Base Unit	**meter**	**meter squared**	**liter**	**gram**	**grams per liter**	**Newtons**	**second**	**meters per second**	**degrees Celcius**
Base Symbol	**m**	**m^2**	**L**	**g**	**g/L**	**N**	**s**	**m/s**	**°C**
Random Fact	The summit of Mount Everest is 8848 meters above sea level and growing.	The area of the United States is 9,629,091,000,000 m^2, which is about 6.5% of all the land found on Earth.	The volume of a gas will expand until it fills its container.	Anything that has mass also has gravity.	The density of a substance depends on its temperature. Objects are generally denser when they are cold.	It is <u>not true</u> that astronauts orbiting the Earth are weightless. They indeed have mass *and* weight, although the weight decreases slightly.	Time moves slower for you when you move faster. A clock mounted higher on the wall moves faster than a clock mounted lower.	Nothing can travel faster than the speed of light, which is 300,000 Km/s (970,000,000 mph). A rocket leaving Earth only travels at 11.2 Km/s.	The coldest possible temperature is -273.15°C and it has never been achieved.

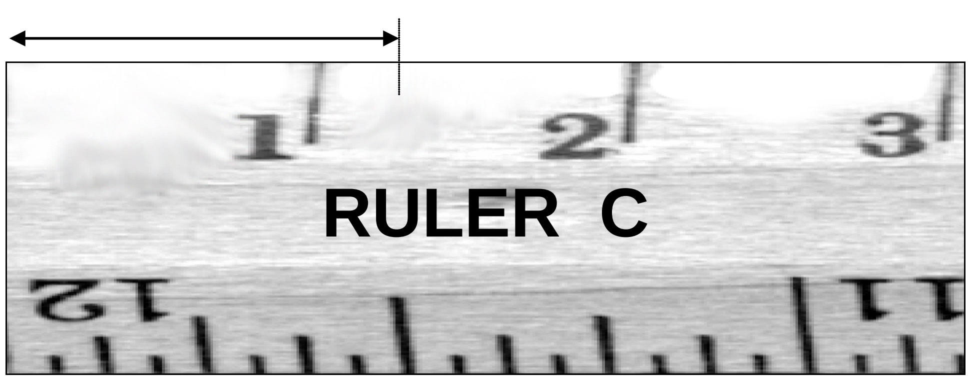
MAKING SCIENTIFIC MEASUREMENTS

As you are aware, scientists and science students performing experiments need to be extremely careful when making measurements so that the data they collect is as accurate and precise as humanly possible. To accurately measure, a person must first understand how to read the measuring device they are using. Ruler A (below) is a ruler that has metric units (centimeters) on the top and standard units (inches) on the bottom, however, scientists generally use only metric units when making measurements. Measure the line below using Ruler A as your ruler.

How long is the line? You are wrong if you say *1 centimeter*. You are even wrong if you say *1.0 centimeters*. The correct length of the line is actually *1.00 centimeters*. The reason why is because scientific measurements always have one **unit of uncertainty**. The unit of uncertainty is always the number that is furthest to the right when the number is written. For example, the unit of uncertainty in 1.00 cm is the second zero to the right of the decimal (1.00). Let's look at another example: how long is the line above Ruler B?



If you said the line above Ruler B is 1.2 cm long, you are wrong. If you said the line above Ruler B is 1.3 cm long, you are also wrong. The line is actually somewhere between 1.20 and 1.30 cm long so it must be written in a way that shows this uncertainty. The way you do this is to imagine that that there are 10 additional lines between each line of the ruler. Looking at Ruler B, it appears that the line extends to just beyond the halfway point between 1.2 and 1.3 cm. Therefore, 1.26 cm is a reasonable estimation for how long the line is. The number 1.26 tells other scientists that you were certain about the first two digits (**1.2**6), but uncertain about the last (1.2**6**). If you were to only write down 1.2 cm, a scientist looking at your data would assume that the last digit (1.**2**) was uncertain and that your ruler must have therefore looked like Ruler C below. That is not good.



Rules for Significant Figures (sig figs, s.f.)

A. Read from the left and start counting sig figs when you encounter the first non-zero digit

1. All non zero numbers are *significant* (meaning they count as sig figs)
   - 613 has three sig figs
   - 123456 has six sig figs

2. Zeros located between non-zero digits are *significant* (they count)
   - 5004 has four sig figs
   - 602 has three sig figs
   - 6000000000000002 has 16 sig figs!

3. Trailing zeros (those at the end) are *significant* only if the number contains a decimal point; otherwise they are *insignificant* (they **don't** count)
   - 5.640 has four sig figs
   - 120000. has six sig figs
   - 120000 has two sig figs – unless you're given additional information in the problem

4. Zeros to left of the first nonzero digit are *insignificant* (they **don't** count); they are only placeholders!
   - 0.000456 has three sig figs
   - 0.052 has two sig figs
   - 0.0000000000000000000000000000000052 also has two sig figs!

B. Rules for addition/subtraction problems

Your calculated value cannot be more precise than the *least precise quantity* used in the calculation. The *least precise quantity* has the fewest digits to the right of the decimal point. **Your calculated value will have the same number of digits to the right of the decimal point as that of the least precise quantity.**
In practice, find the quantity with the fewest digits to the right of the decimal point. In the example below, this would be 11.1 (this is the *least precise quantity*).

7.939 + 6.26 + 11.1 = 25.299 (this is what your calculator spits out)

In this case, your final answer is limited to one sig fig to the right of the decimal or 25.3 (rounded up).

C. Rules for multiplication/division problems

The number of sig figs in the final calculated value will be the same as that of the quantity with the fewest number of sig figs used in the calculation.
In practice, find the quantity with the fewest number of sig figs. In the example below, the quantity with the fewest number of sig figs is 27.2 (three sig figs). Your final answer is therefore limited to three sig figs.

(27.2 x 15.63) ÷ 1.846 = 230.3011918 (this is what you calculator spits out)

In this case, since your final answer it limited to three sig figs, the answer is 230. (rounded down)

D. Rules for combined addition/subtraction and multiplication/division problems

First apply the rules for addition/subtraction (determine the number of sig figs for that step), then apply the rules for multiplication/division.

E. Practice Problems

1. Provide the number of sig figs in each of the following numbers:

(a) 0.0000055 g _____ (c) 1.6402 g _____ (e) 16402 g ______

(b) 3.40 x 10^3 mL ______ (d) 1.020 L _____ (f) 1020 L _______

2. Perform the operation and report the answer with the correct number of sig figs.

(a) (10.3) x (0.01345) = ____________________ (b) (10.3) + (0.01345) = _______________________

(c) [(10.3) + (0.01345)] ÷ [(10.3) x (0.01345)] _____________________________

Appendix A

THE METRIC SYSTEM

The metric system of measurement is used by scientists throughout the world. It is based on units of ten. Each unit is ten times larger or ten times smaller than the next unit. The most commonly used units of the metric system are given below. After you have finished reading about the metric system, try to put it to use. How tall are you in metrics? What is your mass? What is your normal body temperature in degrees Celsius?

Commonly Used Metric Units

Length The distance from one point to another

meter (m)	A meter is slightly longer than a yard. 1 meter = 1000 millimeters (mm) 1 meter = 100 centimeters (cm) 1000 meters = 1 kilometer (km)

Volume The amount of space an object takes up

liter (L)	A liter is slightly more than a quart. 1 liter = 1000 milliliters (mL)

Mass The amount of matter in an object

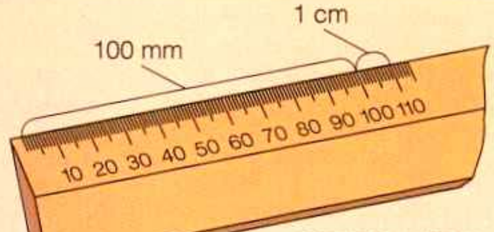
gram (g)	A gram has a mass equal to about one paper clip. 1000 grams = 1 kilogram (kg)

Temperature The measure of hotness or coldness

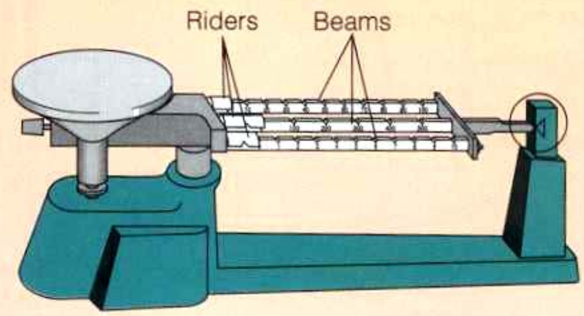
degrees Celsius (°C)	0°C = freezing point of water 100°C = boiling point of water

Metric–English Equivalents

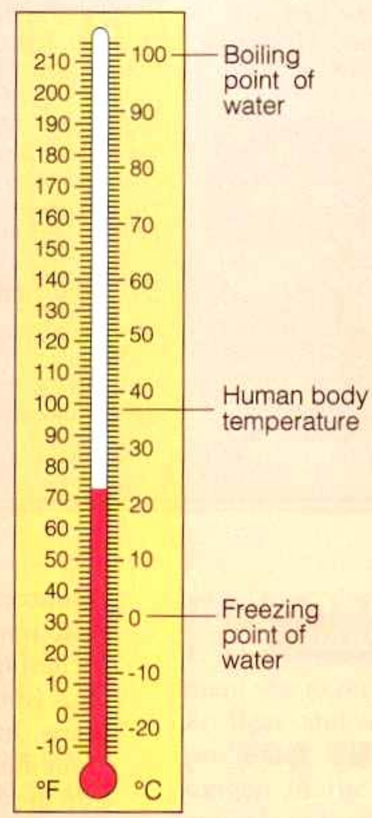
2.54 centimeters (cm) = 1 inch (in.)
1 meter (m) = 39.37 inches (in.)
1 kilometer (km) = 0.62 miles (mi)
1 liter (L) = 1.06 quarts (qt)
250 milliliters (mL) = 1 cup (c)
1 kilogram (kg) = 2.2 pounds (lb)
28.3 grams (g) = 1 ounce (oz)
°C = 5/9 x (°F – 32)



METRIC RULER



TRIPLE-BEAM BALANCE



THERMOMETER

GRADUATED CYLINDER

Length

1 centimeter (cm)	=	10 millimeters (mm)
1 inch	=	2.54 centimeters (cm)
1 foot	=	0.3048 meters (m)
1 foot	=	12 inches
1 yard	=	3 feet
1 meter (m)	=	100 centimeters (cm)
1 meter (m)	≅	3.280839895 feet
1 furlong	=	660 feet
1 kilometer (km)	=	1000 meters (m)
1 kilometer (km)	≅	0.62137119 miles
1 mile	=	5280 ft
1 mile	=	1.609344 kilometers (km)
1 nautical mile	=	1.852 kilometers (km)

Area

1 square foot	=	144 square inches
1 square foot	=	929.0304 square centimeters
1 square yard	=	9 square feet
1 square meter	≅	10.7639104 square feet
1 acre	=	43,560 square feet
1 hectare	=	10,000 square meters
1 hectare	≅	2.4710538 acres
1 square kilometer	=	100 hectares
1 square mile	≅	2.58998811 square kilometers
1 square mile	=	640 acres

Speed

1 mile per hour (mph)	≅	1.46666667 feet per second (fps)
1 mile per hour (mph)	=	1.609344 kilometers per hour
1 knot	≅	1.150779448 miles per hour
1 foot per second	≅	0.68181818 miles per hour (mph)
1 kilometer per hour	≅	0.62137119 miles per hour (mph)

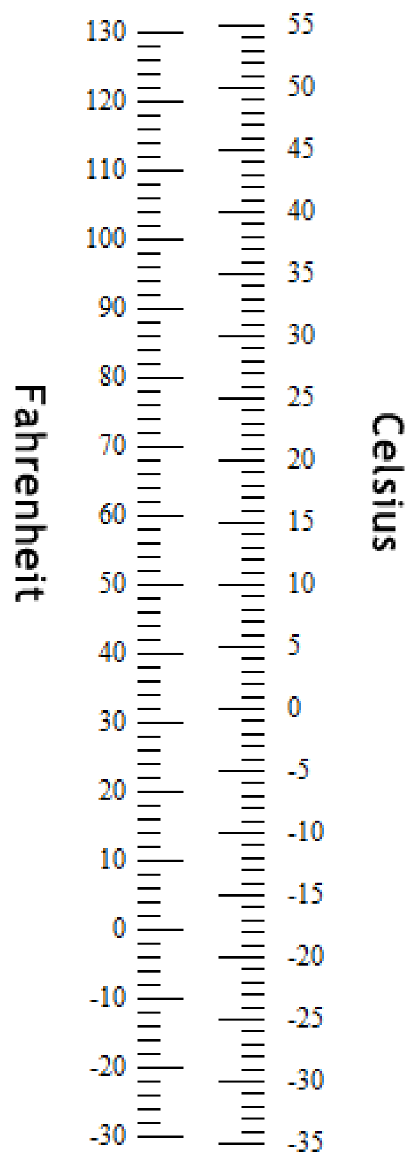
Volume

1 US tablespoon	=	3 US teaspoons
1 US fluid ounce	≅	29.57353 milliliters (ml)
1 US cup	=	16 US tablespoons
1 US cup	=	8 US fluid ounces
1 US pint	=	2 US cups
1 US pint	=	16 US fluid ounces
1 liter (l)	≅	33.8140227 US fluid ounces
1 liter (l)	=	1000 milliliters (ml)
1 US quart	=	2 US pints
1 US gallon	=	4 US quarts
1 US gallon	=	3.78541178 liters

Weight

1 milligram (mg)	=	0.001 grams (g)
1 gram (g)	=	0.001 kilograms (kg)
1 gram (g)	≅	0.035273962 ounces
1 ounce	=	28.34952312 grams (
1 ounce	=	0.0625 pounds
1 pound (lb)	=	16 ounces
1 pound (lb)	=	0.45359237 kilogram
1 kilogram (kg)	=	1000 grams
1 kilogram (kg)	≅	35.273962 ounces
1 kilogram (kg)	≅	2.20462262 pounds (
1 stone	=	14 pounds
1 short ton	=	2000 pounds
1 metric ton	=	1000 kilograms (kg)

Temperature



Los Angeles Times | ARTICLE COLLECTIONS

Mars Probe Lost Due to Simple Math Error

October 01, 1999 | ROBERT LEE HOTZ | TIMES SCIENCE WRITER

NASA lost its $125-million Mars Climate Orbiter because spacecraft engineers failed to convert from English to metric measurements when exchanging vital data before the craft was launched, space agency officials said Thursday.

A navigation team at the Jet Propulsion Laboratory used the metric system of millimeters and meters in its calculations, while Lockheed Martin Astronautics in Denver, which designed and built the spacecraft, provided crucial acceleration data in the English system of inches, feet and pounds.

As a result, JPL engineers mistook acceleration readings measured in English units of pound-seconds for a metric measure of force called newton-seconds.

In a sense, the spacecraft was lost in translation.

"That is so dumb," said John Logsdon, director of George Washington University's space policy institute. "There seems to have emerged over the past couple of years a systematic problem in the space community of insufficient attention to detail."

The loss of the Mars probe was the latest in a series of major spaceflight failures this year that destroyed billions of dollars worth of research, military and communications satellites or left them spinning in useless orbits. Earlier this month, an independent national security review concluded that many of those failures stemmed from an overemphasis on cost cutting, mismanagement, and poor quality control at Lockheed Martin, which manufactured several of the malfunctioning rockets.

But NASA officials and Lockheed executives said it was too soon to apportion blame for the most recent mishap. Accident review panels convened by JPL and NASA are still investigating why no one detected the error.

"It was launched that way," said Noel Hinners, vice president for flight systems at Lockheed Martin's space systems group. "We were transmitting English units and they were expecting metric units. The normal thing is to use metric and to specify that."

None of JPL's rigorous quality control procedures caught the error in the nine months it took the spacecraft to make its 461-million-mile flight to Mars. Over the course of the journey, the miscalculations were enough to throw the spacecraft so far off track that it flew too deeply into the Martian atmosphere and was destroyed when it entered its initial orbit around Mars last week.

John Pike, space policy director at the Federation of American Scientists, said that it was embarrassing to lose a spacecraft to such a simple math error. "It is very difficult for me to imagine how such a fundamental, basic discrepancy could have remained in the system for so long," he said.

"I can't think of another example of this kind of large loss due to English-versus-metric confusion," Pike said. "It is going to be the cautionary tale until the end of time."

At the Jet Propulsion Lab, which owes its international reputation to the unerring accuracy it has displayed in guiding spacecraft across the shoals of space, officials did not flinch from acknowledging their role in the mistake.

"We know this error is the cause," said Thomas R. Gavin, deputy director of JPL's space and earth science directorate, which is responsible for the JPL Mars program. "And our failure to detect it in the mission caused the unfortunate loss of Mars Climate Orbiter.

"When it was introduced and how it was introduced we don't know yet," Gavin said.

NASA officials in Washington were reluctant to blame either Lockheed Martin or JPL solely for the problem, saying that the error arose from a broader quality control failure.

"People make mistakes all the time," said Carl Pilcher, the agency's science director for solar system exploration. "I think the problem was that our systems designed to recognize and correct human error failed us.

"We don't see any connection between this failure and anything else going on at Lockheed Martin," Pilcher said. "This was not a failure of Lockheed Martin. It was systematic failure to recognize and correct an error that should have been caught."

In any event, scientists are anxious that the conversion error does not affect a second spacecraft, the Mars Polar Lander, now approaching the red planet for a landing Dec. 3. The lost orbiter would have served as a radio relay for the lander before beginning its own two-year survey of the Martian atmosphere and seasonal weather.

Data exchanges for the Global Surveyor, which has been orbiting Mars since 1997, have been conducted exclusively in the metric system, Hinners said. Mission controllers expect to use the Surveyor as a relay station in place of the lost orbiter.

If found formally at fault by an accident review board, Lockheed will face financial penalties. But it was not certain Thursday whether Lockheed's contract with JPL actually specified the system of measurements to be used, as many aerospace agreements now often do.

Whatever the contractual consequences for the aerospace company, the loss of the Mars orbiter might have a lasting effect on public confidence in NASA, space analysts said.

Earlier this year, for example, NASA faced public concerns about its Cassini probe as it swung within a celestial hairsbreadth of Earth with an on-board cache of plutonium. The agency's matchless skill in navigating space helped defuse fears of a potentially lethal collision between Earth and the Cassini probe.

Now that skill will be more open to question, analysts said Thursday.

"It is ironic," Logsdon said, "that we can cooperate in space with the Russians and the Japanese and the French but we have trouble cooperating across parts of the United States. Fundamentally, you have partners in this enterprise speaking different languages."