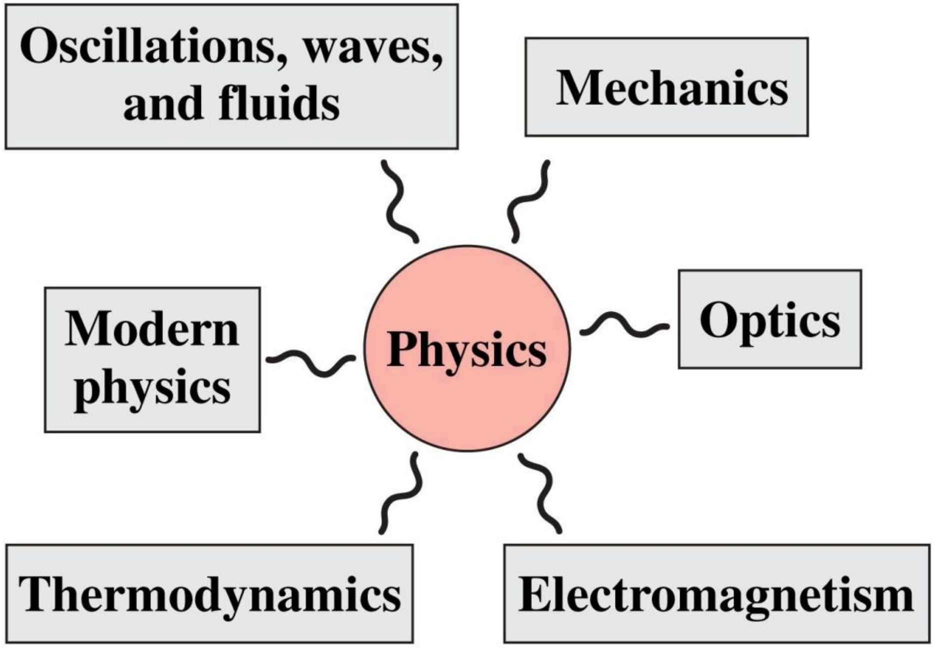
Chapter 1

Measurement

 http://www.youtube.com/watch?v=qxXf7AJZ73A

Realms of Physics

- Physics provides a unified description of basic principles that govern physical reality.
- Fundamental science: motion, force, matter, energy, space, time, …
- Convenient to divide physics into a number of related realms.
  - Here we consider six distinct realms:



- We measure each quantity by its own “unit” or by comparison with a standard.
- **A unit is a measure of a quantity that scientists around the world can refer to.**
- **This has to be both accessible and invariable.**

Example:

1 meter (m) is a unit of length. Any other length can be expressed in terms of 1 meter. A variable length, such as the length of a person’s nose is not appropriate.

1.3 International System of Units (SI)

- The SI system, or the International System of Units, is also called the metric system.
- Three basic quantities are length, time, and mass.
- Many units are derived from this set, as in speed, which is distance divided by time.

Table 1-1

Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

1.3 International System of Units

- **Seven fundamental physical quantities & units:**
  - Length: the meter (m)
  - Time: the second (s)
  - Mass: the kilogram (kg)
  - Electric current: the ampere (A)
  - Temperature: the kelvin (K)
  - Amount of a substance: the mole (mol)
  - Luminous intensity: the candela (cd)
- Supplementary units describe angles:
  - Plane angle: the radian
  - Solid angle: the steradian

1.3 International System of Units

Table 1-2

Prefixes for SI Units

Factor	Prefix[a]	Symbol	Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y	10^{-1}	deci-	d
10^{21}	zetta-	Z	$\mathbf{10^{-2}}$	**centi-**	**c**
10^{18}	exa-	E	$\mathbf{10^{-3}}$	**milli-**	**m**
10^{15}	peta-	P	$\mathbf{10^{-6}}$	**micro-**	**μ**
10^{12}	tera-	T	$\mathbf{10^{-9}}$	**nano-**	**n**
$\mathbf{10^{9}}$	**giga-**	**G**	$\mathbf{10^{-12}}$	**pico-**	**p**
$\mathbf{10^{6}}$	**mega-**	**M**	10^{-15}	femto-	f
$\mathbf{10^{3}}$	**kilo-**	**k**	10^{-18}	atto-	a
10^{2}	hecto-	h	10^{-21}	zepto-	z
10^{1}	deka-	da	10^{-24}	yocto-	y

[a]The most frequently used prefixes are shown in bold type.

Scientific notation expresses results with powers of 10.

Example:

3 560 000 000 m = 3.56×10^{9}m.

Sometimes special names are used to describe very large or very small quantities (as shown in Table 1-2).

Example:

2.35×10^{-9} = 2.35 nanoseconds (ns)

Powers of 10 Simulation:

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

1.4 Changing units

- Based of the base units, we may need to change the units of a given quantity using the chain-link conversion.

- Example: Since there are 60 seconds in one minute,

$$\frac{1\,\mathrm{min}}{60 s} = 1 = \frac{60\,s}{1\,\mathrm{min}}, and$$

$$2\,\mathrm{min} = (2\,\mathrm{min}) x (1) = (2\,\mathrm{min}) x (\frac{60\,s}{1\,\mathrm{min}}) = 120\,s$$

- Conversion between one system of units and another can therefore be easily figured out as shown.

- The first equation above is often called the “conversion factor”.

1.4 Changing units

- Units matter!
- Measures of physical quantities ***must*** always have the correct units.
- Conversion tables (Appendix C of the textbook) give relations between physical quantities in different unit systems:
  - Convert units by multiplying or dividing so that the units you don't want cancel, leaving only the units you do want.
  - Example: Since 1 ft = 0.3048 m, a 5280-foot race (1 mile) is equal to

$$\left(5280\ \mathrm{ft}\right)\frac{0.3048\ \mathrm{m}}{1\ \mathrm{ft}}=1609\ \mathrm{m}$$

  - Example: 1 kilowatt-hour (kWh, a unit of energy) is equivalent to 3.6 megajoules (MJ, another energy unit). Therefore a monthly electric consumption of 343 kWh amounts to

$$\left(343\ \mathrm{kWh}\right)\frac{3.6\ \mathrm{MJ}}{1\ \mathrm{kWh}}=1.23\times 10^{3}\ \mathrm{MJ}=1.23\ \mathrm{GJ}$$

Significant Figures

- The answer to the last example in the preceding slide is 1.23 GJ — not 1234.8 MJ or 1.2348 GJ as your calculator would show.
  - That's because the given quantity, 343 kWh, has only three **significant figures.**
  - That means we know that the actual value is closer to 343 kWh than to 342 kWh or 344 kWh.
  - If we had been given 343.2 kWh, we would know that the value is closer to 343.2 kWh than to 343.1 kWh or 343.3 kWh.
    - In that case, the number given has four significant figures.
  - Significant figures tell how accurately we know the values of physical quantities.
- Calculations can't increase that accuracy, so it's important to report the results of calculations with the correct number of significant figures.

Rules for Significant Figures

- In multiplication and division, the answer should have the same number of significant figures as the least accurate of the quantities entering the calculation.
  - Example: (3.1416 N)(2.1 m) = 6.6 N·m
    - Note the centered dot, normally used when units are multiplied (the kWh is an exception).
- In addition and subtraction, the answer should have the same number of digits to the right of the decimal point as the term in the sum or difference that has the smallest number of digits to the right of the decimal point.
  - Example: 3.2492 m – 3.241 = 0.008 m
    - Note the loss of accuracy as the answer has only one significant figure.

Clicker question

Choose the sequence that correctly ranks the numbers according to the number of significant figures. (Rank from fewest to most.)

A. $0.041\times10^{9},\ 3.14\times10^{7},\ 2.998\times10^{-9},\ 0.0008$

B. $3.14\times10^{7},\ 0.041\times10^{9},\ 0.0008,\ 2.998\times10^{-9}$

C. $2.998\times10^{-9},\ 0.041\times10^{9},\ 0.0008,\ 3.14\times10^{7}$

D. $0.0008,\ 0.041\times10^{9},\ 3.14\times10^{7},\ 2.998\times10^{-9}$

E. $0.0008,\ 0.041\times10^{9},\ 2.998\times10^{-9},\ 3.14\times10^{7}$

1.5 Length

Redefining the meter:

- In 1792 the unit of length, the meter, was defined as one-millionth the distance from the north pole to the equator.

- Later, the meter was defined as the distance between two finely engraved lines near the ends of a standard platinum-iridium bar, the standard meter bar. This bar is placed in the International Bureau of Weights and Measures near Paris, France.

- In 1960, the meter was defined to be 1 650 763.73 wavelengths of a particular orange-red light emitted by krypton-86 in a discharge tube that can be set anywhere in the world.

- In 1983, the meter was defined as the length of the path traveled by light in a vacuum during the time interval of 1/299 792 458 of a second. The speed of light is then exactly 299 792 458 m/s.

Some examples of lengths

Table 1-3

Some Approximate Lengths

Measurement	Length in Meters
Distance to the first galaxies formed	2×10^{26}
Distance to the Andromeda galaxy	2×10^{22}
Distance to the nearby star Proxima Centauri	4×10^{16}
Distance to Pluto	6×10^{12}
Radius of Earth	6×10^{6}
Height of Mt. Everest	9×10^{3}
Thickness of this page	1×10^{-4}
Length of a typical virus	1×10^{-8}
Radius of a hydrogen atom	5×10^{-11}
Radius of a proton	1×10^{-15}

1.5 Length: Estimation

- It's often sufficient to estimate the answer to a physical calculation, giving the result to within an order of magnitude or perhaps one significant figure.

- Estimation can provide substantial insight into a problem or physical situation.

- Example: What's the United States' yearly gasoline consumption?

  - There are about 300 million people in the U.S., so perhaps about 100 million cars (10^8 cars).
  - A typical car goes about 10,000 miles per year (10^4 miles).
  - A typical car gets about 20 miles per gallon.
  - So in a year, a typical car uses (10^4 miles)/(20 miles/gallon) = 500 gal.
  - So the United States' yearly gasoline consumption is about (500 gal/car)(10^8 cars) = 5×10^{10} gallons.

    – That's about 20×10^{10} L or 200 GL.

1.5 Length: Estimation

PROBLEM: The world's largest ball of string is about 2 m in radius. To the nearest order of magnitude, what is the total length, L, of the string of the ball?

SETUP: Assume that the ball is a sphere of radius 2 m. In order to get a simple estimate, assume that the cross section of the string is a square with a side edge of 4 mm. This overestimate will account for the loosely packed string with air gaps.

CALCULATE: The total volume of the string is roughly the volume of the sphere. Therefore,

$$V = (4x10^{-3})^2 x L = \frac{4}{3}\pi R^3 \approx 4R^3$$

$$\Rightarrow L = \frac{4(2m)^3}{(4x10^{-3}m)^2} = 2x10^6 m = 3km$$

1.6 Time

- Atomic clocks give very precise time measurements.
- An atomic clock at the National Institute of Standards and Technology in Boulder, CO, is the standard, and signals are available by shortwave radio stations.

- In 1967 the standard second was defined to be the time taken by:
- 9 192 631 770 oscillations of the light emitted by cesium-133 atom.

Table 1-4

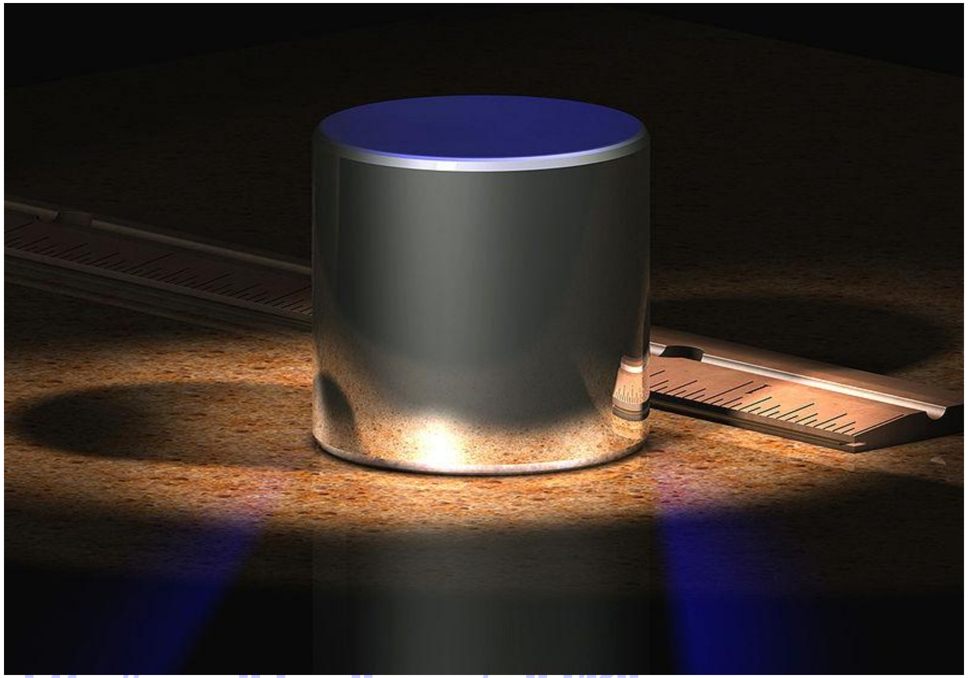
Some Approximate Time Intervals

Measurement	Time Interval in Seconds
Lifetime of the proton (predicted)	3×10^{40}
Age of the universe	5×10^{17}
Age of the pyramid of Cheops	1×10^{11}
Human life expectancy	2×10^{9}
Length of a day	9×10^{4}
Time between human heartbeats	8×10^{-1}
Lifetime of the muon	2×10^{-6}
Shortest lab light pulse	1×10^{-16}
Lifetime of the most unstable particle	1×10^{-23}
The Planck time[a]	1×10^{-43}

[a]This is the earliest time after the big bang at which the laws of physics as we know them can be applied.

1.7 Mass

A platinum-iridium cylinder, kept at the International Bureau of Weights & Measures near Paris, France, has the standard mass of 1 kg.



http://en.wikipedia.org/wiki/Kilogram

Another unit of mass is used for atomic mass measurements. Carbon-12 atom has a mass of 12 atomic mass units, defined as:

$$1u = 1.66053886 x 10^{-27}\ kg$$

Table 1-5

Some Approximate Masses

Object	Mass in Kilograms
Known universe	1×10^{53}
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Small mountain	1×10^{12}
Ocean liner	7×10^{7}
Elephant	5×10^{3}
Grape	3×10^{-3}
Speck of dust	7×10^{-10}
Penicillin molecule	5×10^{-17}
Uranium atom	4×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}

1.7 Density

Density is typically expressed in units of kg/m^3, and is often expressed as the Greek letter, rho (ρ).

Example, Density and Liquefaction:

A heavy object can sink into the ground during an earthquake if the shaking causes the ground to undergo *liquefaction*, in which the soil grains experience little friction as they slide over one another. The ground is then effectively quicksand. The possibility of liquefaction in sandy ground can be predicted in terms of the *void ratio e* for a sample of the ground:

$$e = \frac{V_{\text{voids}}}{V_{\text{grains}}}. \tag{1-9}$$

Here, V_{grains} is the total volume of the sand grains in the sample and V_{voids} is the total volume between the grains (in the *voids*). If e exceeds a critical value of 0.80, liquefaction can occur during an earthquake. What is the corresponding sand density ρ_{sand}? Solid silicon dioxide (the primary component of sand) has a density of $\rho_{SiO_2} = 2.600 \times 10^3$ kg/m^3.

KEY IDEA

The density of the sand ρ_{sand} in a sample is the mass per unit volume—that is, the ratio of the total mass m_{sand} of the sand grains to the total volume V_{total} of the sample:

$$\rho_{\text{sand}} = \frac{m_{\text{sand}}}{V_{\text{total}}}. \tag{1-10}$$

Calculations: The total volume V_{total} of a sample is

$$V_{\text{total}} = V_{\text{grains}} + V_{\text{voids}}.$$

Substituting for V_{voids} from Eq. 1-9 and solving for V_{grains} lead to

$$V_{\text{grains}} = \frac{V_{\text{total}}}{1+e}. \tag{1-11}$$

From Eq. 1-8, the total mass m_{sand} of the sand grains is the product of the density of silicon dioxide and the total volume of the sand grains:

$$m_{\text{sand}} = \rho_{SiO_2} V_{\text{grains}}. \tag{1-12}$$

Substituting this expression into Eq. 1-10 and then substituting for V_{grains} from Eq. 1-11 lead to

$$\rho_{\text{sand}} = \frac{\rho_{SiO_2}}{V_{\text{total}}} \frac{V_{\text{total}}}{1+e} = \frac{\rho_{SiO_2}}{1+e}. \tag{1-13}$$

Substituting $\rho_{SiO_2} = 2.600 \times 10^3$ kg/m^3 and the critical value of $e = 0.80$, we find that liquefaction occurs when the sand density is less than

$$\rho_{\text{sand}} = \frac{2.600 \times 10^3 \text{ kg/m}^3}{1.80} = 1.4 \times 10^3 \text{ kg/m}^3.$$

(Answer)

A building can sink several meters in such liquefaction.