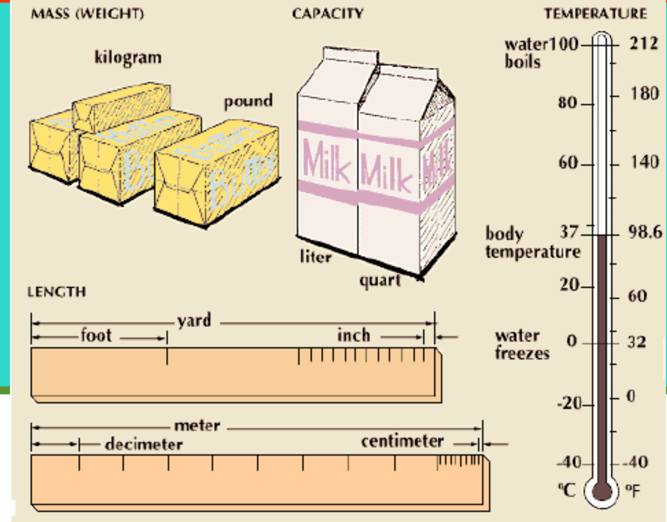
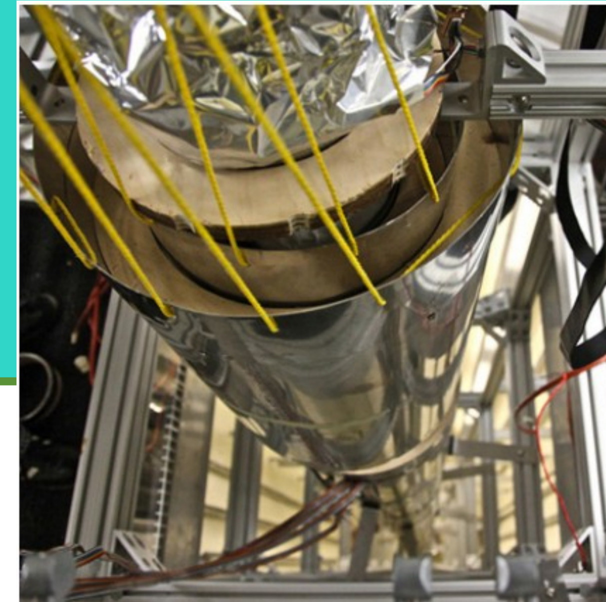
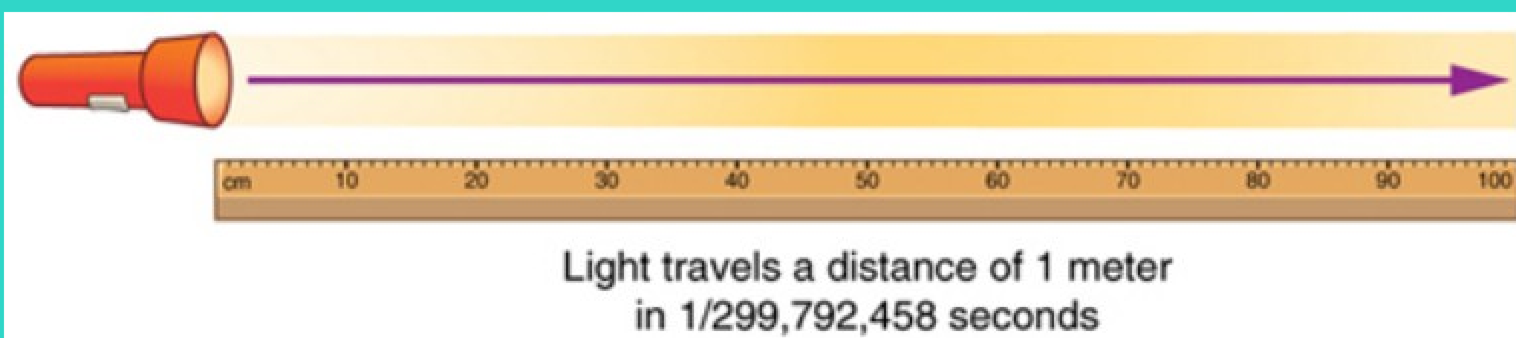
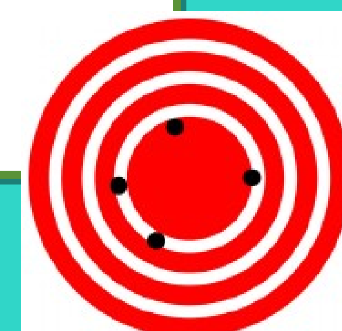


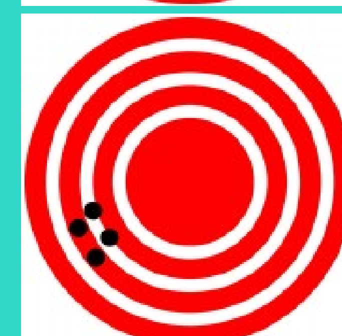
Chapter 1



Measurement







İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ

İZMİR KATİP ÇELEBİ ÜNİVERSİTESİ

1 MEASUREMENT 1

- Scientific Notation
- Significant Figures
- Chain Rule
- Error, Uncertainty, Error Propagation
- Accuracy, Precision

Important Topics

- Physics and engineering are based on the **precise** measurement of physical quantities (mass, time, length, pressure, etc.).
- 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.
  - A standard . This has to be both accessible and invariable.
    - For 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.
- Base quantities:
  - **Seven fundamental quantities.**
  - Three are needed for mechanics: **length, time, mass**.
  - All have been assigned standards.
  - Are used to define all other physical quantities.

- If you want to communicate about your measurements with others in the world, you need to agree upon some **Standard Units** of measurements.
- SI Units used to be called MKS system of units. In this course we will use International system of units (SI or Système International). It is also known as **metric system**.

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	**10^{-2}**	**centi-**	**c**
10^{18}	exa-	E	**10^{-3}**	**milli-**	**m**
10^{15}	peta-	P	**10^{-6}**	**micro-**	**μ**
10^{12}	tera-	T	**10^{-9}**	**nano-**	**n**
10^{9}	**giga-**	**G**	**10^{-12}**	**pico-**	**p**
10^{6}	**mega-**	**M**	10^{-15}	femto-	f
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** uses the power of 10.
  - 3 560 000 000 m = 3.56 x 10^9 m.
- Sometimes special names are used to describe very large or very small quantities (Table 1-2).
  - 2.35 x 10^{-9} = 2.35 nanoseconds (ns)

- ***Length, Mass and Time***, units for these parameters are regarded as ***base units***. (SI base units are **m**, **kg**, and **s**)

Table 1-1

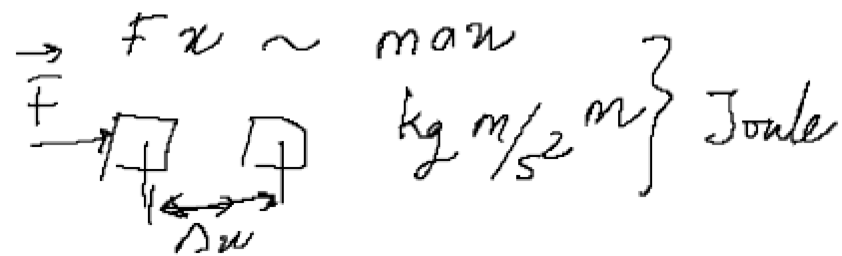
Units for Three SI Base Quantities

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

- Units for other parameters are defined in terms of these **base units** and are called ***derived units***

Joules (work-energy): 1 J = 1 kg m^2/s^2

Watts (power): 1 W = 1 J/s = 1 kg m^2/s^3



- Based of the base units, we may need to change the units of a given quantity using the chain-link conversion.
- Generally it is done by multiplying original measurement by a conversion factor.
- For example, since there are 60 seconds in one minute,

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

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

- <u>Chain-link conversions</u>:
  - 1.3 km x (1000 m)/(1 km) = 1300 m = 1.3 x 10^3 m
  - 0.8 km x (1000 m)/(1 km) x (100 cm)/(1 m) = 80 000 cm = 8 x 10^4 cm
  - 2845 mm x (1 m)/(1000 mm) x (3.281 ft)/(1 m) = 9.334 ft

Example: Find the distance that light travels in one year.

$c = 2.998 \times 10^8\ m/s$ light year, ly

Base Unit: time $1 = \frac{60\ sec}{1\ min}$, $1 = \frac{365.25\ day}{1\ year}$, $1\ ly = (2.998 \times 10^8\ m/s)(year)$

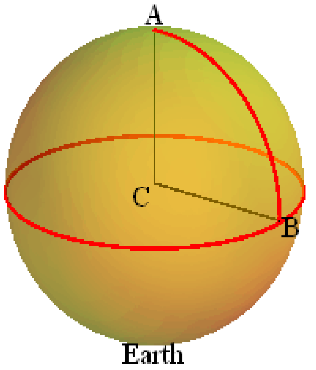
$$1\ ly = (2.998 \times 10^8\ m/s)(1\ year)\left(\frac{365.25\ day}{1\ year}\right)\left(\frac{24\ hours}{1\ day}\right)\left(\frac{60\ min}{1\ hour}\right)\left(\frac{60\ sec}{1\ min}\right)$$

$$= 9.461 \times 10^{15}\ m$$

Light year in meter

in one single line!

- Unit of length: "Meter" was originally defined in terms of the distance measured along the earth's surface between **North pole** (point A) and **Equator** (Point B).
  - 1 meter ≡ AB/10 000000



- Eventually, a more accurate standard was needed, and by international agreement the meter became *the distance between two marks on a bar of platinum-iridium alloy kept at 0 °C.*

- Today meter is defined as *the distance traveled by light in vacuum during a time interval of 1/299 792 458 of a second.*
  - This definition arises because the **speed of light** is a **universal constant** and is defined to be 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}

- Any standard of time needs to be able to answer:
  - *When* did a thing happen?
  - What was *its duration*?
- Standards of time in the past have included:
  - Rotation of Earth
  - Quartz vibrations
- Atomic clocks (cesium), with time signals sent out by radio so others can calibrate their clocks. One second is the time taken by 9192631770 oscillations of the light (of a specified wavelength) emitted by a 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.

- Today one kilogram is defined to be the mass of a standard cylinder of platinum-iridium alloy, kept at the international Bureau of weights and measures in Sèvres, France.
- The **atomic mass unit** (u) is a second mass standard.
    - It is the carbon-12 atom, which, by international agreement, has been assigned a mass of 12 atomic mass units.
    - 1 atom of Carbon-12 is assigned a mass 12 u
    - Used for measuring masses of atoms and molecules
    - 1 u = 1.660 538 86 x 10^{-27} kg (+/- 10 x 10^{-35} kg)

Error bound

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}

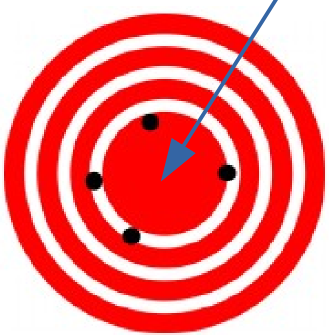
1-7 Mass, Density

- Mass per unit volume is called **density**.
- Density is typically expressed in kg/m^3, and is often expressed as the Greek letter, rho (ρ).

$$\rho = \frac{m}{V}$$

- Calculate . . .
  - Density of material: (18 kg) / (0.032 m^3) = 560 kg/m^3
  - Mass of object: (380 kg/m^3) x (0.0040 m^3) = 1.5 kg
  - Volume of object: (250 kg) / (1280 kg/m^3) = 0.20 m^3

- **Accuracy** is *how close* a measurement is *to the correct value* for that measurement.
- *Exact/Correct value*: 11.0 3 significant figures (sf)
  - *Measurements*: 11.1, 11.2, and 10.9. These measurements are quite **accurate** because they are very close to the correct value of 11.0.
- The **precision** of a measurement system is refers to *how close* the agreement is between *repeated measurements* (which are repeated under the same conditions).



Low precision.

High accuracy.

- Uncertainty: $A \pm \delta A$
- Percent Uncertainity:
  % unc $= \delta A/A \times 100\%$

100 ± 1

1000 ± 1

High precision.

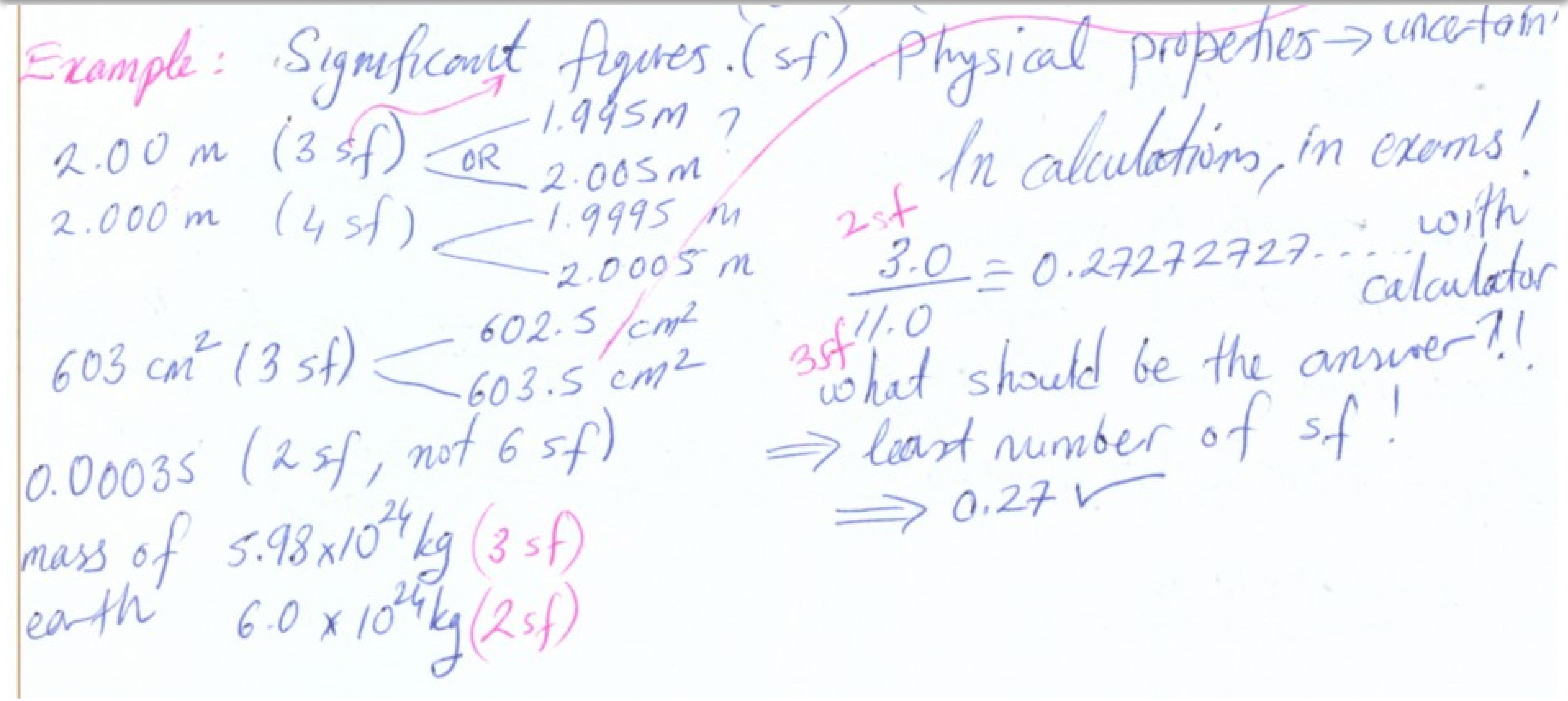
Low accuracy.

- **Scientific notation** is used to express the *very large* and *very small* quantities. Non-zero numbers are significant! (but with care)
  - **Example 1:** 0.00035 (two significant digits)
  - **Example 2:** 0.000325400 (six significant digits)
  - **Example 3:** 2500 (two significant digits)
    - In general, trailing zeros are not significant.
    - In other words, 2500 *may* have 4 significant figures
    - but usually 2500 will have only 2 significant figures!
    - When in doubt, use scientific notation 2.500 x 10^3 or 2.5×10^3
  - **Example 4:** 3560 000 000 (three significant digits)
  - **Example 5:** 356.00 (five significant digits)
- **Scientific notation** employs powers of 10 to write large or small numbers

$$3\,560\,000\,000 \text{ m} = 3.56 \times 10^9 \text{ m}$$

$$0.000\,000\,492 \text{ s} = 4.92 \times 10^{-7} \text{ s.}$$

- **Significant figures** <u>are meaningful digits</u>. Generally, round to *the least number of significant figures* of the given data (see next slide),
  - 25 x 18 → 2 significant figures; 25 x 18975 → still 2
  - Round up for 5+ (13.5 → 14, but 13.4 → 13)



Addition, Substraction: round to *the least precise place* of the given data

3.0+11.01=14.01 –> 14.0

Multiplication, Division: round to *the least number of significant figures* of the given data

Example: Chain Link

Example: Find the distance that light travels in one year.

$c = 2.998 \times 10^8\ m/s$ light year, ly

4 sf

Base Unit: time $1 = \frac{60\ sec}{1\ min}$, $1 = \frac{365.25\ day}{1\ year}$, $1\ ly = \frac{(2.998 \times 10^8\ m/s)}{(year)}$

$$1\ ly = (2.998 \times 10^8\ m/s)(1\ year)\left(\frac{365.25\ day}{1\ year}\right)\left(\frac{24\ hours}{1\ day}\right)\left(\frac{60\ min}{1\ hour}\right)\left(\frac{60\ sec}{1\ min}\right)$$

$$= 9.461 \times 10^{15}\ m$$

4 sf

Example: Uncertainity, How accurate!

Page width? a measure: 1 mm divisions (accuracy)

21.6 cm — 0.1 cm

21.6 ± 0.1 cm plus minus 0.1 : Error in measurement

Percentage error in measurement : $\left(\frac{0.1}{21.6}\right) \times 100 = 0.5\ \%$

Page area?

21.6 cm (± 0.1)

27.9 cm (± 0.1)

(0.4%) what is the percentage error in measurement?

$(21.6\ cm) * (27.9\ cm) = 603\ cm^2$

what about uncertainity in measurement of area?

(0.4 + 0.5) addition 0.9 → 0.9 %

$(0.9) * (603\ cm^2) = 5\ cm^2 \Rightarrow 603 \pm 5\ cm^2$

c±δc

Minimum division is 1 mm in ruler.

Uncertainity in Result.

Simple Expression: δa+δb !

- Double Page Width: $21.6 \pm 0.1\,cm \rightarrow 2(21.6 \pm 0.1\,cm) = 43.2 \pm 0.2\,cm$
- (Summation / Substraction) of Page Widths: $(21.6 \pm 0.1\,cm, 27.9 \pm 0.1\,cm) \rightarrow (A \pm \Delta A, B \pm \Delta B)$

$\Rightarrow C = A + B$ & $\Delta C = \sqrt{\Delta A^2 + \Delta B^2} = \sqrt{0.1^2 + 0.1^2} = 0.14 \sim 0.1$

$\Rightarrow D = B - A$ & $\Delta D = \sqrt{\Delta A^2 + \Delta B^2} = \sqrt{0.1^2 + 0.1^2} = 0.14 \sim 0.1$

$\rightarrow C = 49.5 \pm 0.1\,cm$ & $D = 6.3 \pm 0.1\,cm$

In general: $E = a + b + \dots + z - (X + Y + \dots + Z) \rightarrow \Delta E = \sqrt{\underbrace{\delta a^2 + \delta b^2 + \dots + \delta z^2 + \delta X^2 + \delta Y^2 + \dots + \delta Z^2}_{\text{all in summation}}}$

- (Multiplication / Division) of Page Widths: $A * B = C$ & $\Delta C = |C| \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2}$

$C = 21.6 * 27.9 = 603\,cm^2$ & $\Delta C = 603\,cm^2 \sqrt{\left(\frac{0.1}{21.6}\right)^2 + \left(\frac{0.1}{27.9}\right)^2}$

$\Rightarrow \underline{603 \pm 4\,cm^2}$

$= (603\,cm^2)(0.006) = 3.6 \sim 4$

- Raised to a Power: $C = A^n$; $21.6 \pm 0.1\,cm$; say $n = 3$

$\Delta C = C|n| \frac{\Delta A}{A} \rightarrow \Delta C = A^3 |3| \frac{0.1}{21.6}$

- Any Function: function $\rightarrow \sin\theta$ with $\theta \pm \Delta\theta$

$\Delta f \sim \left|\frac{df}{d\theta}\right| \Delta\theta = \cos\theta\, \Delta\theta$ $\Big\}$ $\sin\theta \pm (\cos\theta\, \Delta\theta)$

We generally round uncertainties to one significant figure anyway,

Example:

$$A = \frac{(11.2 \pm 0.1m)(16.8 \pm 0.2m)}{(5222 \pm 5\ sec)} \rightarrow \Delta A = |A| \sqrt{\left(\frac{0.1}{11.2}\right)^2 + \left(\frac{0.2}{16.8}\right)^2 + \left(\frac{5}{5222}\right)^2}$$

$$\rightarrow \frac{11.2 \times 16.8}{5222} = 0.036032171531769 \quad = 0.0360(0.0149117244535\ldots) = 0.0005$$

3 sig figs → 0.0360; 0.0005 in 1 sig fig.

$$\Rightarrow A \pm \Delta A = 0.0360 \pm 0.0005$$

Example: A ball is tossed straight up into the air with initial speed $v_0 = 4.0 \pm 0.2\ m/s$. After a time $t = 0.60 \pm 0.06\ s$, the height of the ball is $y = v_0 t - \frac{1}{2} g t^2 = 0.636\ m$. What is the uncertainty of y? Assume $g = 9.80\ m/s^2$ (no uncertainty) How many sf?

$\rightarrow y = a - b \rightarrow a = v_0 t$ & $b = \frac{1}{2} g t^2$

$a \pm \Delta a$: $a \Rightarrow (4.0 \pm 0.2\ m/s)(0.60 \pm 0.06\ s) \Rightarrow \Delta a = |a| \sqrt{\left(\frac{0.2}{4.0}\right)^2 + \left(\frac{0.06}{0.60}\right)^2}$

$a = 2.4\ m$ (2 sf?) & $\Delta a = (2.4m)\sqrt{(0.05)^2 + (0.10)^2} = (2.4m)(0.112)$ ($0.111803\ldots$) $= 0.27m$

$b \pm \Delta b$: $b \Rightarrow \frac{1}{2}(9.8\ m/s^2)(0.60 \pm 0.06\ s)^2 \Rightarrow \Delta b = b |2| \left(\frac{0.06}{0.6}\right) = (1.764)(2)(0.10) = 0.35\ m$

$b = 1.764\ m$ (4 sf?)

3 sf?

$\Rightarrow y = a - b = 0.636$ & $\Delta y = \sqrt{(0.27m)^2 + (0.35\ m)^2} = 0.442040\ldots$

$$\boxed{0.64 \pm 0.44}$$ 2 sf √

1. Spacing in this book was generally done in units of points and picas: 12 points = 1 pica, and 6 picas = 1 inch. If a figure was misplaced in the page proofs by 0.80 cm, what was the misplacement in (a) picas and (b) points?

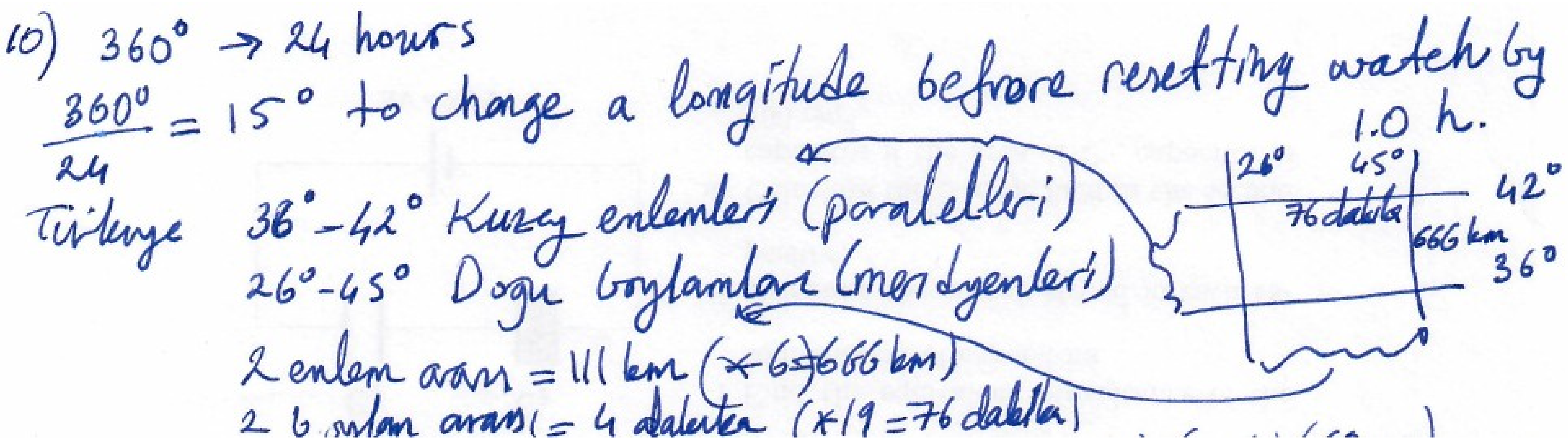
4) 1 inch = 2.54 cm
6 picas = 1 inch
12 points = 1 pica } Conversion factors

Misplaced by 0.80 cm ⇒ in terms of i) picas ? ii) points ?

i) $(0.80\,cm) = (0.80\,cm)\left(\frac{1\,inch}{2.54\,cm}\right)\left(\frac{6\,picas}{1\,inch}\right) \simeq 1.89\,picas$

ii) $(0.80\,cm) = (0.80\,cm)\left(\frac{1\,inch}{2.54\,cm}\right)\left(\frac{6\,picas}{1\,inch}\right)\left(\frac{12\,points}{1\,pica}\right) \cong 22.7\,points$

2. Travelers reset their watches only when the time change equals 1.0 h. How far, on the average, must you travel in degrees of longitude between the time-zone boundaries at which your watch must be reset by 1.0 h? (*Hint:* Earth rotates 360° in about 24 h.)



3. A lecture period (50 min) is close to 1 microcentury. (a) How long is a microcentury in minutes? (b) Using

$$\text{percentage difference} = \left(\frac{\text{actual} - \text{approximation}}{\text{actual}}\right)100,$$

find the percentage difference from the approximation.

14) i) $1\,\mu\,\text{century} = (10^{-6}\,\text{century})\left(\frac{100\ \text{years}}{1\ \text{century}}\right)\left(\frac{365\ \text{day}}{1\ \text{year}}\right)\left(\frac{24\ \text{h}}{1\ \text{day}}\right)\left(\frac{60\ \text{min}}{1\ \text{h}}\right) = 52.6\ \text{min}$

Close to 50 min!

ii) $\left(\frac{52.6\ \text{min} - 50\ \text{min}}{52.6\ \text{min}}\right) \times 100 = 4.9\,\%$: percentage difference

4. Earth has a mass of $5.98\text{x}10^{24}$ kg. The average mass of the atoms that make up Earth is 40 u. How many atoms are there in Earth?

21) $m_E = 5.98\times10^{24}\,kg$

Average mass of the atom : 40 u

1 au = mass of Carbon-12

$\Rightarrow 1.661\times10^{-27}\,kg$

$$Mass_{Earth} = N * \bar{m}_{atom}$$

$$N = \frac{5.98\times10^{24}\,kg}{40\,u\left(\frac{1.661\times10^{-27}\,kg}{1\,u}\right)} = 9.0\times10^{49}\text{ atoms}$$

N: number of atoms

5. Gold, which has a density of 19.32 g/cm³, is the most ductile metal and can be pressed into a thin leaf or drawn out into a long fiber. (a) If a sample of gold, with a mass of 27.63 g, is pressed into a leaf of 1.000 μm thickness, what is the area of the leaf? (b) If, instead, the gold is drawn out into a cylindrical fiber of radius 2.500 μm, what is the length of the fiber?

22) $\rho_{gold} = 19.32\ g/cm^3$ Ductile metal

i) $m = 27.63\ g$ → a leaf of 1.000 μm thickness ⇒ Area = ?

$$\rho = \frac{m}{V} \rightarrow V = A * d = \frac{m}{\rho} = \frac{27.63\ g}{19.32\ g/cm^3} = 1.43\ cm^3$$

(A = area, d = thickness)

$$A * \left(1\ \mu \frac{10^{-6}\ m}{1\ \mu}\right) = 1.43\ cm^3 \left(\frac{10^{-6}\ m^3}{1\ cm^3}\right) \Rightarrow \boxed{Area \cong 1.43\ m^2}$$

ii) $r = 2.500\ \mu m$ → cylindrical wire → length = ?

$$V_{cylinder} = (\pi r^2 l) \rightarrow l = \frac{V_{cylinder}}{\pi r^2} = \frac{m/\rho}{\pi r^2} = \frac{1.43\ cm^3 \left(\frac{10^{-6}\ m^3}{1\ cm^3}\right)}{(3.14)\left(2.500\ \mu m\ \frac{10^{-6}\ m}{1\ \mu m}\right)^2}$$

$$\rightarrow length \cong \frac{1.43\ m}{3.14 * (2.500)^2 \times 10^{-6}} = 72.83 \times 10^3\ m$$

$\boxed{\sim 73\ km}$

Measurement

- Defined by relationships to base quantities
- Each defined by a standard, and given a unit

Changing Units

- Use chain-link conversions
- Write conversion factors as unity
- Manipulate units as algebraic quantities

Time

- Second is defined in terms of oscillations of light emitted by a cesium-133 source
- Atomic clocks are used as the time standard

Density

- Mass/volume

$$\rho = \frac{m}{V}$$ **Eq. (1-8)**

SI Units

- International System of Units
- Each base unit has an accessible standard of measurement

Length

- Meter is defined by the distance traveled by light in a vacuum in a specified time interval

Mass

- Kilogram is defined in terms of a platinum-iridium standard mass
- Atomic-scale masses are measured in u, defined as mass of a carbon-12 atom

Additional Materials

How we measure?

Bu soru Kopenhag'daki bir Üniversitenin fizik sınavından alınmıştır: «Bir gökdelenin yüksekliğini barometre ile nasıl bulursunuz, anlatınız.»

1. "Barometrenin ucuna bir ip bağlarsınız sonra gökdelenin tepesinden asıp sallarsınız. Barometre yere değdiğinde ipin boyuyla barometrenin boyunun toplamı gökdelenin yüksekliğini verecektir."
2. "İlk olarak, barometreyi gökdelenin tepesine çıkartıp kenarından aşağı bırakıp yere inene kadar gecen sureyi ölçersiniz. Binanın yüksekliği ($H=1/2gt^2$) formülü uygulanarak hesaplanabilir. Fakat barometre için kotu bir secim..."
3. "Veya güneş parlıyorsa, barometrenin yüksekliğini ölçersiniz. Sonra onu bir yere dikip gölge uzunluğunu ve sonra da gökdelenin gölge uzunluğunu ölçebilirsiniz. Bundan sonrası basit bir orantıyı çözmek olacaktır."
4. "Fakat bu konuda gök bilimsel bir cevap istiyorsanız barometrenin ucuna bir sicim bağlayıp onu bir sarkaç gibi sallandırabilirsiniz; önce yer seviyesinde daha sonra da gökdelenin tepesinde. Yüksekliği $T=2\pi\,(L/g)^{1/2}$ formülündeki farktan yararlanarak bulabilirsiniz."
5. "Yahut da gökdelenin dışarısında bir yangın çıkış merdiveni varsa barometreyi bir cetvel gibi kullanarak yukarıya çıkarken gökdelenin boyunu barometre yüksekliği biriminden sayıp bunları toplayabilirsiniz."
6. "Eğer ille de ortodoks çözüm istiyorsanız, tabii ki barometre ile gökdelenin tepesindeki ve yer seviyesindeki basıncı ölçer milibar cinsinden çıkan farkı feet'e çevirebilirsiniz ve yüksekliği bulursunuz."

How we measure?

“Ancak bizler daima zihnin bağımsızlığı ve bilimsel metotlar kullanma konusunda teşvik edildiğimiz içindir ki en iyi yol şüphesiz hademenin kapısını çalmak ve yeni bir barometre isteyip istemediğini sorarak gökdelenin yüksekliğini söylemesi durumunda ona bu barometreyi vereceğimizi söylemek olurdu.”

Bu cevapla sınıfını geçen öğrencinin adı:

Niels Bohr,

Fizikte nobel ödülü kazanan tek Danimarkalı...

TABLE 1

The SI Base Units

Quantity	Name	Symbol	Definition
length	meter	m	"... the length of the path traveled by light in vacuum in 1/299,792,458 of a second." (1983)
mass	kilogram	kg	"... this prototype [a certain platinum–iridium cylinder] shall henceforth be considered to be the unit of mass." (1889)
time	second	s	"... the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom." (1967)
electric current	ampere	A	"... that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length." (1946)
thermodynamic temperature	kelvin	K	"... the fraction 1/273.16 of the thermodynamic temperature of the triple point of water." (1967)
amount of substance	mole	mol	"... the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12." (1971)
luminous intensity	candela	cd	"... the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian." (1979)

TABLE 2

Some SI Derived Units

Quantity	Name of Unit	Symbol	
area	square meter	m^2	
volume	cubic meter	m^3	
frequency	hertz	Hz	s^{-1}
mass density (density)	kilogram per cubic meter	kg/m^3	
speed, velocity	meter per second	m/s	
angular velocity	radian per second	rad/s	
acceleration	meter per second per second	m/s^2	
angular acceleration	radian per second per second	rad/s^2	
force	newton	N	$kg \cdot m/s^2$
pressure	pascal	Pa	N/m^2
work, energy, quantity of heat	joule	J	$N \cdot m$
power	watt	W	J/s
quantity of electric charge	coulomb	C	$A \cdot s$
potential difference, electromotive force	volt	V	W/A
electric field strength	volt per meter (or newton per coulomb)	V/m	N/C
electric resistance	ohm	Ω	V/A
capacitance	farad	F	$A \cdot s/V$
magnetic flux	weber	Wb	$V \cdot s$
inductance	henry	H	$V \cdot s/A$
magnetic flux density	tesla	T	Wb/m^2
magnetic field strength	ampere per meter	A/m	
entropy	joule per kelvin	J/K	
specific heat	joule per kilogram kelvin	$J/(kg \cdot K)$	
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	
radiant intensity	watt per steradian	W/sr	

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,

$$V=\left(4 x 10^{-3}\right)^2 x\ L=\frac{4}{3}\pi\ R^3 \approx 4 R^3$$

$$\Rightarrow L=\frac{4\left(2\ m\right)^3}{\left(4 x\ 10^{-3} m\right)^2}=2\ x\ 10^6 m=3\ km$$