Lecture 1

Units

- How we measure things....
- All things in classical mechanics can be expressed in terms of the "fundamental" or "base" units:
  - Length L
  - Mass M
  - Time T
- For example:
  - Speed has units of L / T (i.e. miles per hour). (m/s) Derived units are combinations of base units
  - Force has units of ML / T^2 etc... (as you will learn). $\vec{F} = m \cdot \vec{a}$

Distance → [m]

Table 1.1

TABLE 1.1 Selected Distances in Meters (m)

Description	Distance (m)
Distance to farthest galaxy (estimated)	1×10^{26}
Diameter of our Milky Way galaxy	9×10^{20}
Distance light travels in 1 year	9.5×10^{15}
Mean distance from Earth to Sun	1.5×10^{11}
Earth's mean radius	6.4×10^{6}
Tallest mountain on Earth	8800
Typical adult human height	1.5 to 2.0
Wavelength of visible light	4.0×10^{-7} to 7.0×10^{-7}
Diameter of hydrogen atom	1.1×10^{-10}
Size of proton (approximate)	10^{-15}

Mass

AP Images/Jacques Brinon

a

Table 1.2 Approximate Values of Some Masses

	Mass (kg)
Observable Universe	1×10^{52}
Milky Way galaxy	7×10^{41}
Sun	2×10^{30}
Earth	6×10^{24}
Moon	7×10^{22}
Shark	1×10^{2}
Human	7×10^{1}
Frog	1×10^{-1}
Mosquito	1×10^{-5}
Bacterium	1×10^{-15}
Hydrogen atom	2×10^{-27}
Electron	9×10^{-31}

Table 1.3

TABLE 1.3 Selected Masses in Kilograms (kg)

Typical galaxy	10^{42}
Sun	2.0×10^{30}
Earth	6.0×10^{24}
Blue whale	1.5×10^{5}
Adult human	50 to 100
Flea	10^{-5}
Dust particle	10^{-14}
Uranium atom	4.0×10^{-25}
Proton	1.7×10^{-27}
Electron	9.1×10^{-31}

Time

AP Images/Focke Strangmann

b

Table 1.3 Approximate Values of Some Time Intervals

	Time Interval (s)
Age of Universe	5×10^{17}
Age of Earth	1×10^{17}
Age of college student	6×10^{8}
One year	3×10^{7}
One day	9×10^{4}
Heartbeat	8×10^{-1}
Audible sound wave period[a]	1×10^{-3}
Typical radio wave period[a]	1×10^{-6}
Visible light wave period[a]	2×10^{-15}
Nuclear collision	1×10^{-22}

[a]A *period* is defined as the time required for one complete vibration.

Chapter 1 – Measurements in Physics
Dimensional analysis

One of the simplest methods of checking the result of a calculation is looking at the dimensions that come out. Dimensions are basic types of quantities such as: length [L], time [T], or mass [M].

The square brackets indicate dimensions, not units.

Even before checking the numbers, if the dimensions do not correspond to the quantity calculated, then there is a mistake somewhere.

One of the most efficient ways to avoid mistakes is to calculate symbolically until the final steps where you plug in the numbers and the units. The units can easily be compared with the expected dimensions.

Simple examples include:

- Surface $[L]^2 \rightarrow square{:}x[L] \cdot x[L], rectangle{:}x[L] \cdot y[L], circle{:}\pi r[L] \cdot r[L]$
- Volume $[L]^3 \rightarrow Add\ a\ 3rd\ dimension\ to\ surface;\ e.g.\ cube{:}x[L] \cdot x[L] \cdot x[L], sphere{:}\frac{4}{3}\pi r^3$
- Speed $\frac{[L]}{[T]} \rightarrow \frac{m}{s}, \frac{miles}{hour}$
- Acceleration $\frac{[L]}{[T]^2} \rightarrow \frac{m}{s^2}, \frac{ft}{s^2}$

Chapter 1 – Measurements in Physics
Units and conversions: distance, time, and mass

- There are many non-SI units that are used in science, and they are accepted for use together with SI ones.
- Pay attention when converting them and using their values in calculations!
- The most common ones that will be used in this course are:

Quantity	Name of unit	Symbol for unit	Value in SI units
time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3600 s
	day	d	1 d = 24 h = 86 400 s
plane angle	degree	$^\circ$	$1^\circ = (\pi/180)$ rad
	minute	$'$	$1' = (1/60)^\circ = (\pi/10\,800)$ rad
	second	$''$	$1'' = (1/60)' = (\pi/648\,000)$ rad
area	hectare	ha	$1\ \text{ha} = 1\ \text{hm}^2 = 10^4\ \text{m}^2$
volume	litre	L, l	$1\ \text{L} = 1\ \text{l} = 1\ \text{dm}^3 = 10^3\ \text{cm}^3 = 10^{-3}\ \text{m}^3$
mass	tonne	t	$1\ \text{t} = 10^3\ \text{kg}$

Unit Conversions for Physical Quantities

$1\ \text{mi} = 1\,609\ \text{m} = 1.609\ \text{km}$

$1\ \text{ft} = 0.304\,8\ \text{m} = 30.48\ \text{cm}$

$1\ \text{m} = 39.37\ \text{in.} = 3.281\ \text{ft}$

$1\ \text{in.} = 0.025\,4\ \text{m} = 2.54\ \text{cm}$

Convert 15.0 in. to centimeters.

$$1\ \text{in.} = 2.54\ \text{cm} \rightarrow \frac{2.54\ \text{cm}}{1\ \text{in.}}$$

$$15.0\ \cancel{\text{in}}. \times \left(\frac{2.54\ \text{cm}}{1\ \cancel{\text{in}}.}\right) = 38.1\ \text{cm}$$

Scientific Notation

Standard decimal notation	Normalized scientific notation
2	2×10^0
300	3×10^2
4,321.768	$4.321\,768 \times 10^3$
-53,000	-5.3×10^4
6,720,000,000	6.72×10^9
0.2	2×10^{-1}
0.000 000 007 51	7.51×10^{-9}

Table 1.4

TABLE 1.4 Some SI Prefixes*

Power of 10	Prefix	Abbreviation
10^{-18}	Atto	a
10^{-15}	Femto	f
10^{-12}	Pico	p
10^{-9}	Nano	n
10^{-6}	Micro	μ
10^{-3}	Milli	m
10^{-2}	Centi	c
10^{3}	Kilo	k
10^{6}	Mega	M
10^{9}	Giga	G
10^{12}	Tera	T
10^{15}	Peta	P
10^{18}	Exa	E

*For a more complete list, see Appendix B.

Chapter 1 – Measurements in Physics
Significant figures

One of the consequences of limited precision and accuracy is that real-life measurements and calculations can often be available with a limited number of digits in the scientific notation.

- The human eye can be reliable to read a ruler at ~ 0.5 mm. So, measuring the length of a stretched paper clip with a ruler we can say that it is 51.5 mm long. It could really be just 51.25 mm, or it could be 51.75 mm, but we are certain that it is longer than 51.0 mm, and shorter than 52.0 mm. This we claim to be a number with 3 significant digits, even if the real number can vary by almost 1 mm (± 0.5 mm).

- However, if we measure an object of 8.5 mm, so the real result is larger than 8.0 mm smaller than 9.0 mm, with the same 1 mm (± 0.5 mm) precision, then we can only claim 2 significant digits.

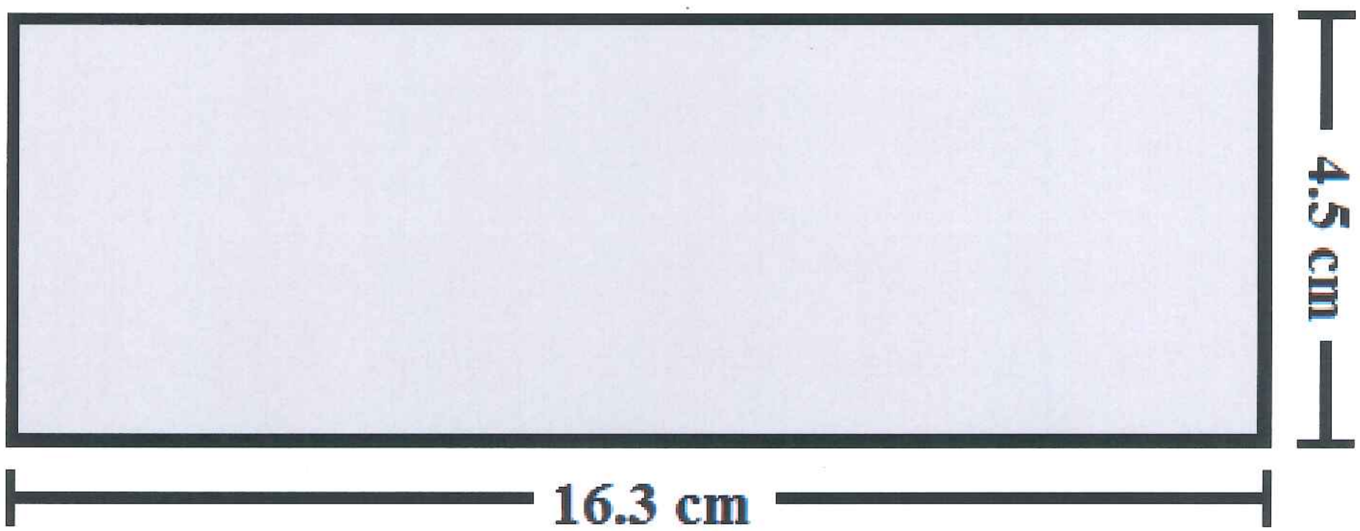
- On the plus side, if we measure 285.5 mm with the same ruler, we can claim 4 significant digits, because the precision is kept at 1mm.

- Leading zeroes are not significant figures. Trailing zeroes should be treated with care. Any zeroes between non-zero numbers are significant figures.

- Calculation example:

$$1.51m + 4.5mm = \frac{1510.0mm}{0004.5mm} += 1.5145m, \textit{ but we claim 1.51 m.}$$

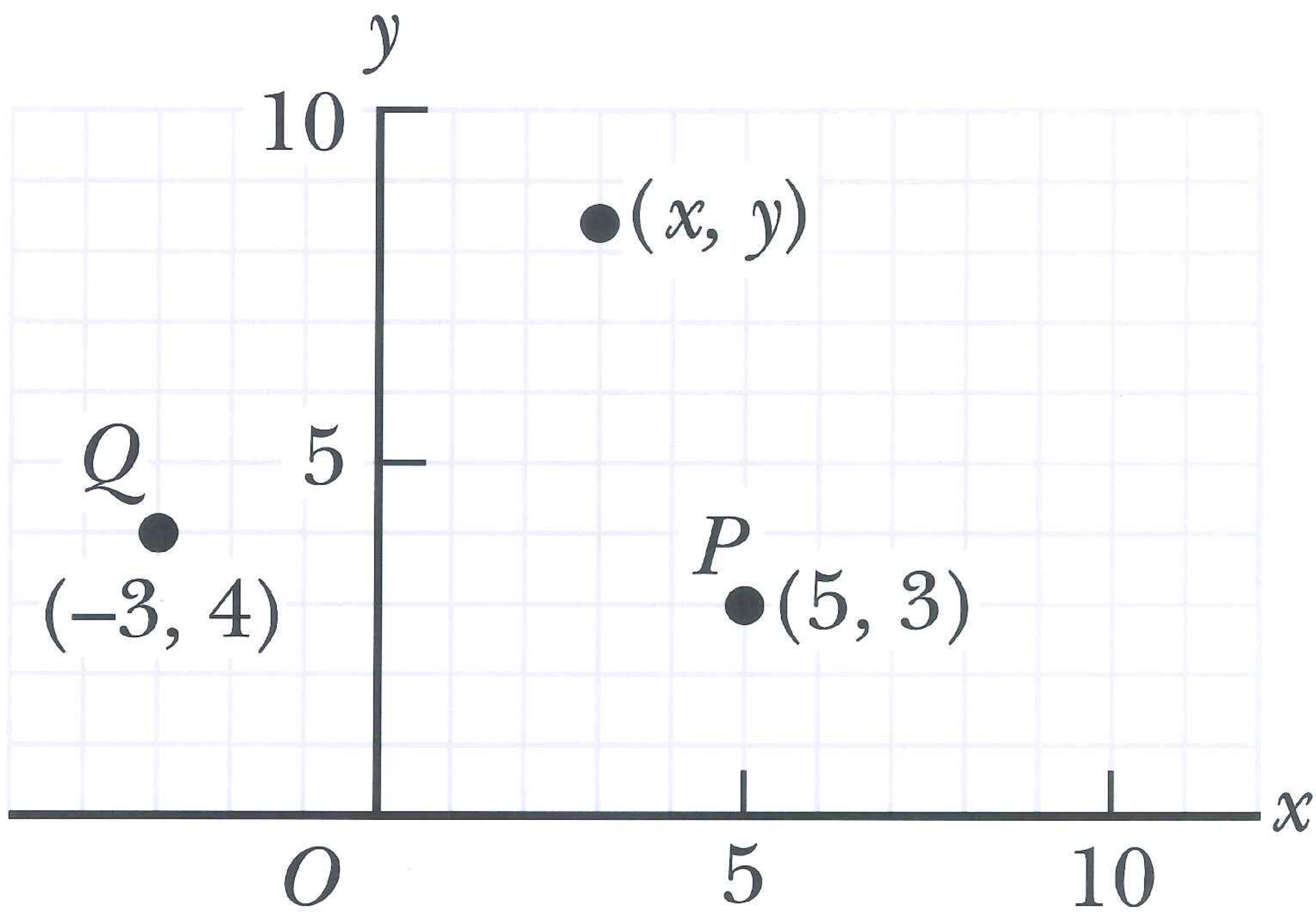
Uncertainty in Measurement and Significant Figures



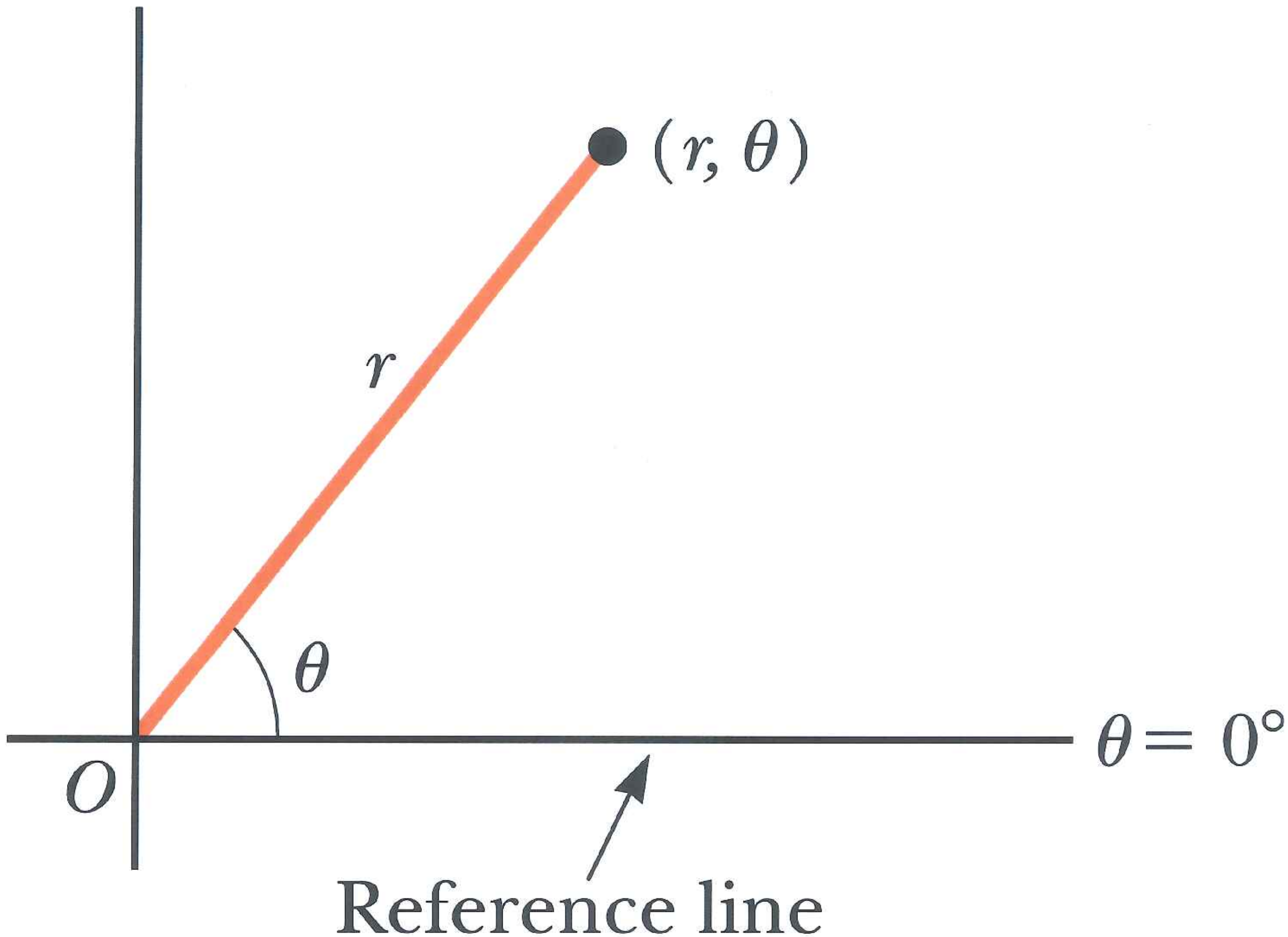
$$L = 16.3 \pm 0.1 \text{ cm} \qquad W = 4.5 \pm 0.1 \text{ cm}$$

$$L \times W = (16.3 \text{ cm})(4.5 \text{ cm}) = 73.35 \text{ cm}^2 \rightarrow 73 \text{ cm}^2$$

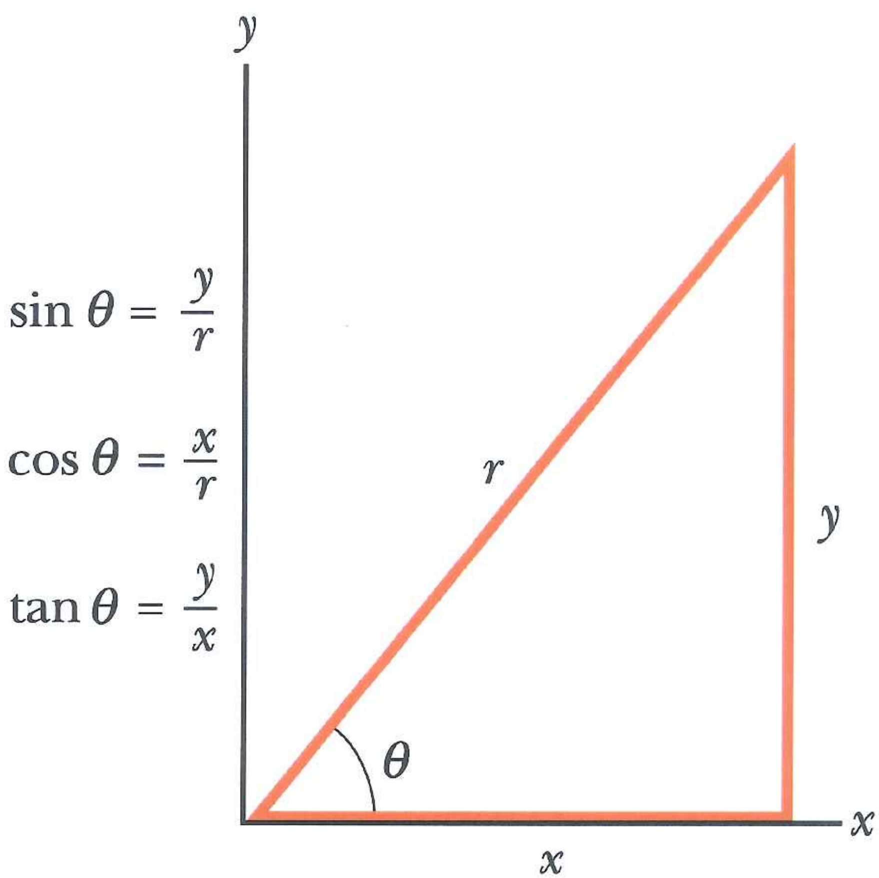
Coordinate Systems



Coordinate Systems



Trigonometry Review



$$\sin\theta = \frac{\text{side opposite } \theta}{\text{hypotenuse}} = \frac{y}{r}$$

$$\cos\theta = \frac{\text{side adjacent } \theta}{\text{hypotenuse}} = \frac{x}{r}$$

$$\tan\theta = \frac{\text{side opposite } \theta}{\text{side adjacent } \theta} = \frac{y}{x}$$

Pythagorean theorem:

$$x^2 + y^2 = r^2$$

Trigonometry Review

Example:

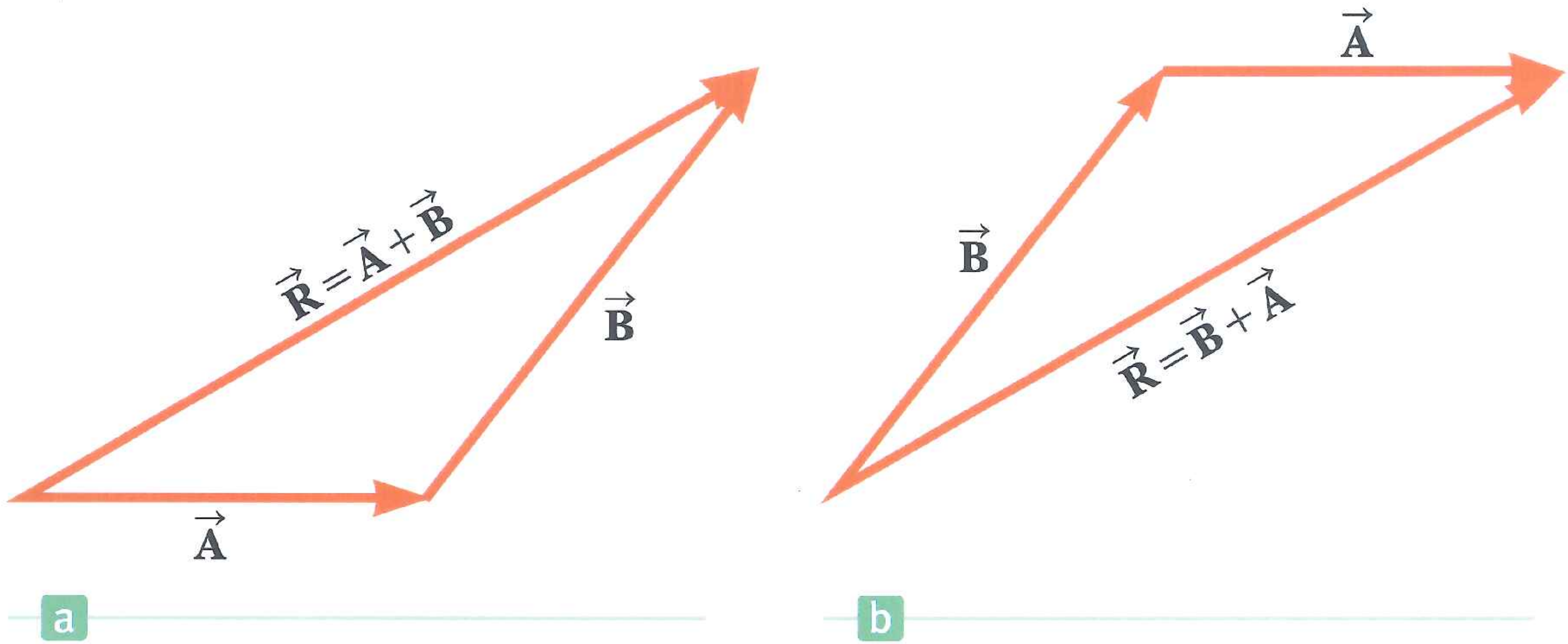
$$\sin\theta = 0.866 \rightarrow \text{ What is } \theta \text{ ?}$$

$$\sin^{-1}(0.866) = \theta = 60.0°$$

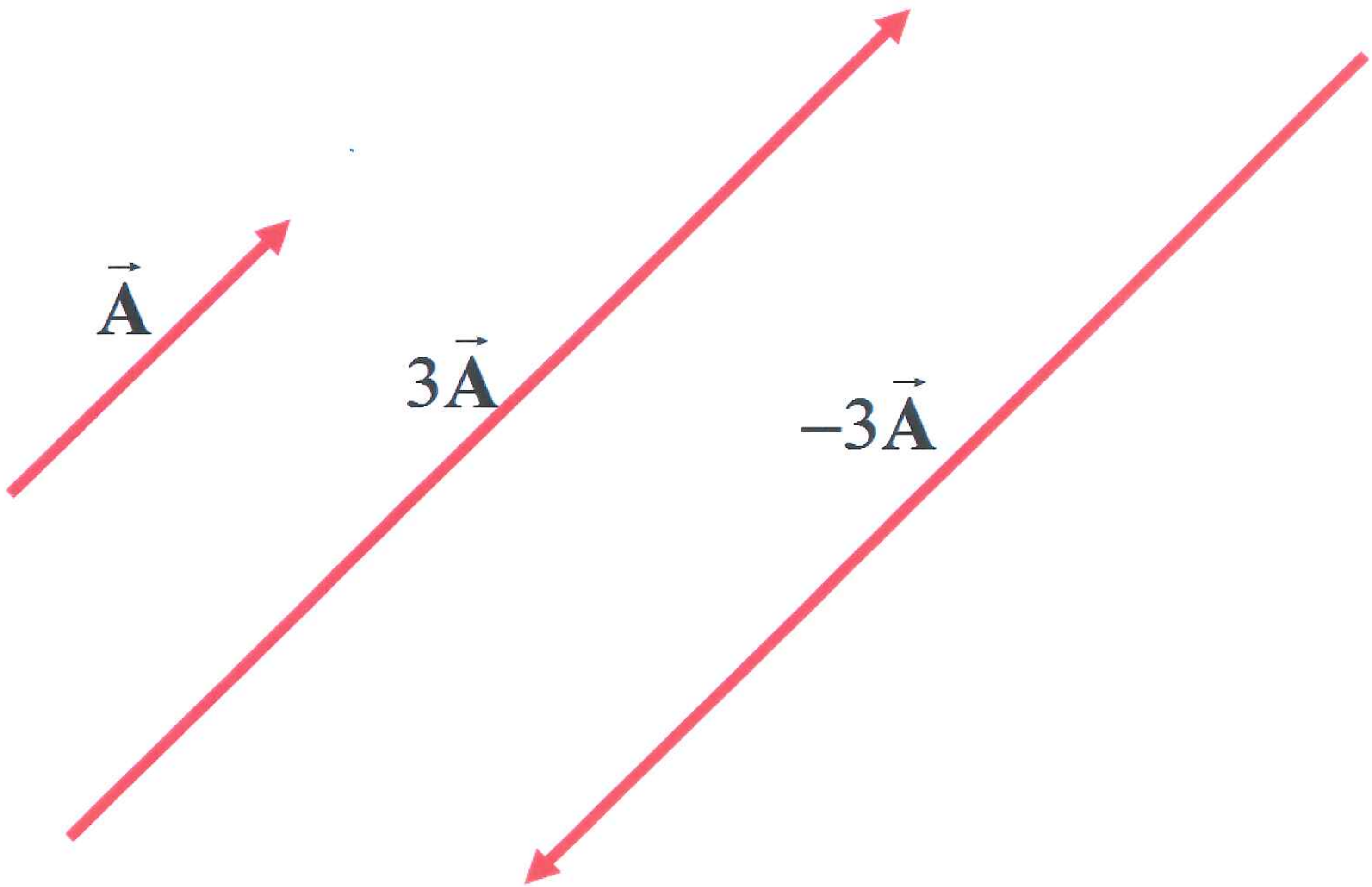
Example:

$$\tan^{-1}(0.400) = \theta = 21.8°$$

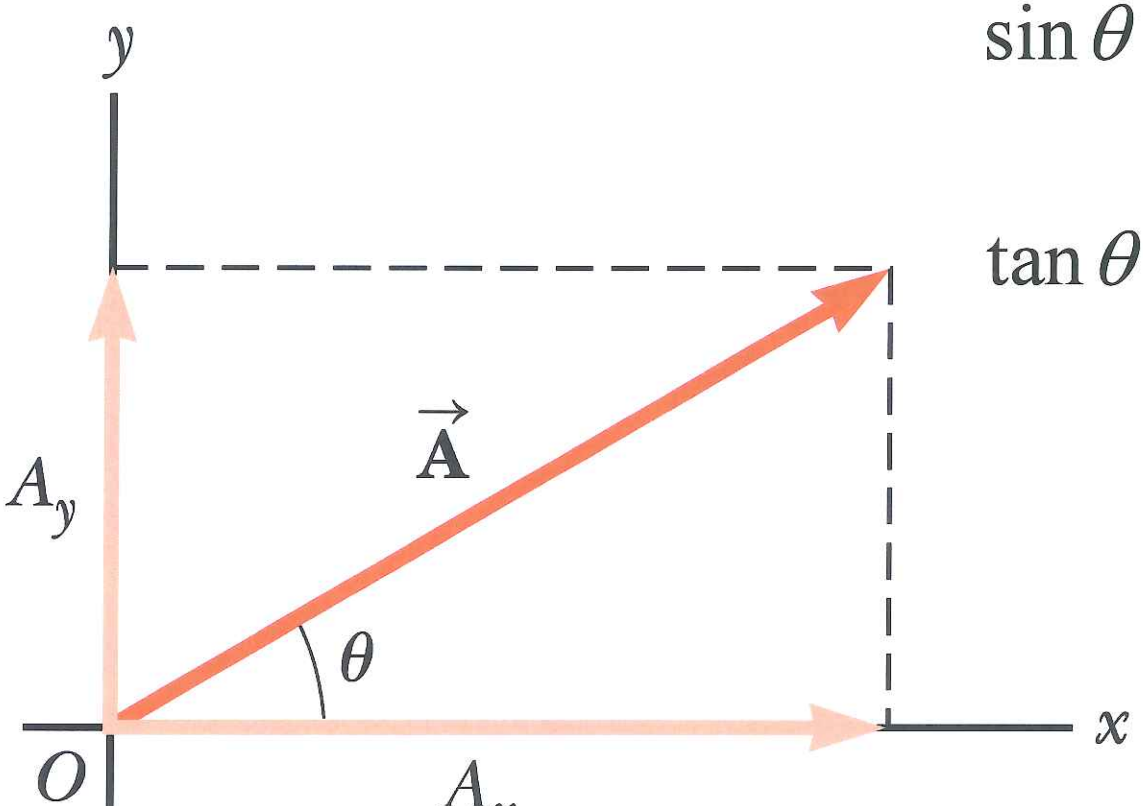
Adding Vectors



Multiplying or Dividing a Vector by a Scalar



Components of a Vector



$$\cos\theta = \frac{A_x}{A} \rightarrow A\cos\theta = A_x$$

$$\sin\theta = \frac{A_y}{A} \rightarrow A\sin\theta = A_y$$

$$\tan\theta = \frac{A_y}{A_x}$$

$$A_x^{\,2} + A_y^{\,2} = A^2$$

$$\rightarrow A = \sqrt{A_x^{\,2} + A_y^{\,2}}$$

Fundamental Constants

Speed of light = 299,792,458 m/s ~ 300, 000 km/s

Measurement and uncertainty

Accuracy: How close a measurements is to the true value

Precision: Refers to the uncertainty of an individual measurement. Usually increased by taking several measurements are averaging them out.

Order of magnitude estimates

Example: How long does it take to travel a distance of 5,000 km with a speed of 90 km/h.

Solution: Time = distance/speed = 5,000 Km/(90 km/h) = 5.55 h ~56 h

There are 24 h in a day. Therefore, estimated travel time ~ 2.3 days

DVD ~ 8 GBytes 1 G = 10^9

A CD-ROM disk can store approximately 600.0 megabytes of information. If an average word requires 9.0 bytes of storage, how many words can be stored on one disk?

$$1M = 10^6$$

$$\text{Stored Information} = 600*10^6 \text{ bytes}$$

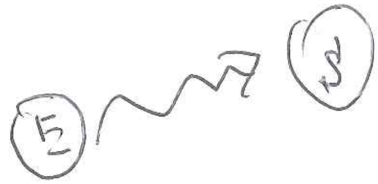
$$\#\#\text{ words} = 600*10^6 \text{ bytes}/9.0 = 6.7*10^7 \text{ words}$$

25. **SOLVE** The ratio of Earth's radius and the height of Mount Everest's summit (8847 m) is:

$$\frac{h(\text{Mount Everest})}{r(\text{Earth})} = \frac{(8847\text{ m})}{(6.371\times 10^{6}\text{ m})} = 1.39\times 10^{-3}$$

$$\mathbf{1\% = 1/100 = 10^{-2}}$$

REFLECT The height of Mount Everest makes up only about 0.1% of Earth's radius.



1M = 10^6 m

1B = 10^{12} m

6. SOLVE Based on the average distance between Earth and Saturn of 1.2 billion km, there will be a time delay between the moment a radio signal is sent and the time the spacecraft receives the signal:

$$t = \frac{(1.2 \times 10^{12} \text{ m})}{(299792458 \text{ m s}^{-1})} = 4002.8 \text{ s} = 66.7 \text{ min}$$

Furthermore, the radio frequency signals travel on a straight pass, therefore, communication with the spacecraft will be lost when it is on the opposite side of Saturn.

speed of light =

299792458 $\frac{m}{s}$

Problem-Solving Strategy

1. Read problem
2. Draw diagram
3. Label physical quantities
4. Identify principle(s); list data
5. Choose equation(s)
6. Solve equation(s)
7. Substitute known values
8. Check answer