Chapter 1

Physics and Measurements

Length, Mass, and Time

- These are the three fundamental quantities mechanics is concerned about
- All other quantities in mechanics can be expressed in terms of these three
  - distance: it's length, too (length of a pole = distance between its ends)
  - width, height, depth: it's all length
  - frequency: how many times something occurs per unit time (so it's defined through time)
  - speed: distance traveled per unit time
  - temperature: mechanics doesn't care ☺

Measurements and Standards

- Physics wants to measure everything
  - measure = assign a number
- Measurements are relative: we compare properties of an objet to something we already know
  - a tree is as tall as a ten-storey building
  - the FAST radio telescope is as large as 30 football fields
- To make measurements reproducible, the results should be compared to standards, which must
  - be readily accessible
  - yield the same result anywhere in the Universe
  - not change with time

Time

- Unit: second
- Old definition: $\left(\frac{1}{24}\right)\left(\frac{1}{60}\right)\left(\frac{1}{60}\right)$ of mean solar day
  - can’t use this definition away from Earth
  - Earth rotation is irregular and slowing down
- Modern definition: 9 192 631 770 × period of vibration of radiation from the Cesium-133 atom
  - it’s “indirect” because what’s measured is frequency, not the time interval – but that’s OK ($T=1/f$)
  - it’s practical (easy to make a clock), works everywhere in the Universe, and is perfectly stable (as far as we know)

Length

- Unit: meter
- Old definitions:
  - fraction of Earth's perimeter
  - artifact-based – a bar stored in France
  - wavelength of orange-red light emitted by a Krypton-86 lamp
- Modern definition: the distance traveled by light in vacuum during 1/299 792 458 second
  - speed of light is postulated (and can't be measured)
  - there is no need to have two separate standards – it follows from a deep relation between space and time revealed by the special theory of relativity

Mass

- Unit: kilogram
- Old definition
  - artifact-based – a special alloy cylinder kept in France
- Modern definition
  - it's still the same ☹
- What to do? Follow the meter ☺
  - Avogadro project: fix the mass of an atom (Silicon-28)
  - Watt balance: fix Planck's constant
- No official decision yet

Dimensional Analysis

- Two reasons to do it:
  - weed out errors in calculations
  - evaluate dependencies between the quantities
- Is the formula for position $x = \frac{1}{2}at^2$ correct?
  - $[a]=L/T^2$ $[t]=T$ $[x]=L$ – correct ☺
- If we know acceleration and time, how could position depend on them?
  - if there are no other factors, we can assume that $x = a^n t^m$
  - $L=(L/T^2)^n T^m$ $n=1$; $m-2n=0 \rightarrow m=2$ $x \sim at^2$

SI Units

- Fundamental units: meter m, kilogram kg, second s
- Prefixes: Xm, Xg, Xs, where X is one of SI symbols below:

SI PREFIX	SI SYMBOL	SI UNIT CONVERSION FACTOR (STANDARD FORM)	FACTOR (POWER)	FACTOR LANGUAGE
yotta	Y	1 yottametre = 1 000 000 000 000 000 000 000 000 metres	10^{24}	septillion
zetta	Z	1 zettametre = 1 000 000 000 000 000 000 000 metres	10^{21}	sextillion
exa	E	1 exametre = 1 000 000 000 000 000 000 metres	10^{18}	quintillion
peta	P	1 petametre = 1 000 000 000 000 000 metres	10^{15}	quadrillion
tera	T	1 terametre = 1 000 000 000 000 metres	10^{12}	trillion
giga	G	1 gigametre = 1 000 000 000 metres	10^{9}	billion
mega	M	1 megametre = 1 000 000 metres	10^{6}	million
kilo	k	1 kilometre = 1 000 metres	10^{3}	thousand
hecto	h	1 hectometre = 100 metres	10^{2}	hundred
deca	da	1 decametre = 10 metres	10^{1}	ten
		1 metre = 1 metre	$\mathbf{10^{0}}$	**one**
deci	d	1 decimetre = 0.1 metres	10^{-1}	tenth
centi	c	1 centimetre = 0.01 metres	10^{-2}	hundredth
milli	m	1 millimetre = 0.001 metres	10^{-3}	thousandth
micro	µ	1 micrometre = 0.000 001 metres	10^{-6}	millionth
nano	n	1 nanometre = 0.000 000 001 metres	10^{-9}	billionth
pico	p	1 picometre = 0.000 000 000 001 metres	10^{-12}	trillionth
femto	f	1 femtometre = 0.000 000 000 000 001 metres	10^{-15}	quadrillionth
atto	a	1 attometre = 0.000 000 000 000 000 001 metres	10^{-18}	quintillionth
zepto	z	1 zeptometre = 0.000 000 000 000 000 000 001 metres	10^{-21}	sextillionth
yocto	y	1 yoctometre = 0.000 000 000 000 000 000 000 001 metres	10^{-24}	septillionth

Conversion of Units

- Simple conversions:
  - 10 in = 10 in (2.54 cm/1 in) = 25.4 cm
  - 2 cm = 2 cm (1 in/2.54 cm) = 0.787 in
- Complex conversions:
  - 1 m^2 = 1 m^2 (100 cm / 1 m)^2 = 10 000 cm^2
  - 1 m/s = 1 m/s (1 km/1000 m)/(1 h/3 600 s) = 3.6 km/h
  - 60 mi/h = 60 mi/h (1 609 m/1 mi)/(3 600 s/1 h) = 29 m/s

Scientific Notation

- Scientific notation = a number expressed in form $a \times 10^b$
  - can be done in more than one way
- Normalized scientific notation: $1 \le a < 10$
  - not defined for zero
  - if $b=0$, the 10^b factor is omitted
- Engineering notation: b is a multiple of 3
  - makes it easy to match prefixes

Order of Magnitude Estimates

- Order of magnitude estimate = a power of ten
- Prescription:
  - write the number in normalized scientific notation: $x = a \times 10^b$
  - if $a < \sqrt{10}$, $x \sim 10^b$, otherwise $x \sim 10^{b+1}$

Significant Figures

- When quantities are measured, the results are known within experimental uncertainty
- 15 000 m – not clear
  - should we trust all 5 digits? (probably not)
- 1.5×10^4 m – better
  - there are just two digits to trust (could be anywhere between 14 500 m and 15 500 m)
  - 1.5×10^4 m and 1.50×10^4 m mean different things
- $(1.5\pm0.1)\times10^4$ m – a lot of information
  - in a paper, this would mean that the probability that the actual quantity is between 14 900 m and 15 100 m is 68%

Operations with Approximate Numbers

- When adding/subtracting, keep the smallest number of decimal places
  - 1.40 + 2.41 = 3.81 (3 s.d. + 3 s.d. -> 3 s.d.)
  - 1.4 + 2.41 = 3.8 (2 s.d. + 3 s.d. -> 2 s.d.)
  - $1.205 - 1.203 = 2\times10^{-3}$ (4 s.d. – 4 s.d. -> 1 s.d.)
  - 12.05 – 1.203 = 10.85 (4 s.d. – 4 s.d. -> 4 s.d.)
- When multiplying/dividing, keep the smallest number of significant digits
  - 1.40 × 2.41 = 3.37 (3 s.d. × 3 s.d. -> 3 s.d.)
  - $\pi(2.1)^2 = 14$ (s.d. × 2 s.d. -> 2 s.d.)