PC1221 Fundamentals of Physics I
Semester-1, AY09/10

course website: http://www.physics.nus.edu.sg/~phytaysc/pc1221_09

Lectures 1 and 2
Introduction, Historical Overview and Measurement

A/Prof Tay Seng Chuan

Ground Rules

- Switch off your handphone and pager
- Switch off your laptop computer and keep it
- No talking while lecture is going on
- No gossiping while the lecture is going on
- Raise your hand if you have question to ask
- Be on time for lecture
- Be on time to come back from the recess break to continue the lecture
- Bring your lecture notes to lecture

Introduction of Lecturer

A/Prof Tay Seng Chuan
Tel: 65168752
Email: scitaysc@nus.edu.sg
Office: S16-02, Dean’s Office at Level 2
URL: http://www.physics.nus.edu.sg/~phytaysc

Current Duties in NUS:
Day: Associate Professor (Physics), Head of Faculty IT Unit (Science), Coordinator for SM2/SM3 Programmes (MOE), Associate Director (Office of Alumni Relations) representing Temasek Hall. I am also a regular project mentor of Science Mentorship Programme for Secondary School students (MOE Gifted Education Programme).
Night: Assistant Master of Temasek Hall, Bursar, Resident Fellow (Block E).

Consultation for PC1221
Day: S16-02, Dean’s Office. By email (scitaysc@nus.edu.sg) or telephone call (65168752) for appointment. It is better to give a telephone call before you come to see me. I would appreciate that you will indentify yourself when you call me.
Night: Temasek Hall, Block E, Unit E100. Please make appointment in advance if you need to consult me at night so that I will be waiting for you.
Assessments for this module

- 5 sets of lab report – 20%
- 2 Tests (Closed Book) – 20%
  (Tentatively on Week 5 and Week 9)
- Final Exam (Closed Book) – 60%

Textbooks (Have been reserved at the Science library at Red Spot Section)


Complementary books:


Contents

- This module is for students without Physics qualifications at GCE “A” level or its equivalent. You should not take this module if you have “A” level Physics or its equivalent
- In this module I will introduce you to only two main topics in Physics:
  - Mechanics
  - Thermodynamics

How we are going to do it

- 2 lectures/week
  (1 hour and 45 minutes/session)
- 5 Laboratory sessions (3 hours/session)
- 5 Tutorial sessions (45 minutes/session)
- 2 Tests (40 minutes each)
- Consultation
  (mass consultation and appointment)
- Final exam (2 hours)
Timetable

### SEMESTER 1

<table>
<thead>
<tr>
<th>Orientation Period</th>
<th>Mon 03 Aug 2009 - Sat 05 Dec 2009</th>
<th>18 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>Mon 10 Aug 2009 - Fri 14 Aug 2009</td>
<td></td>
</tr>
<tr>
<td>Week 2</td>
<td>Mon 17 Aug 2009 - Fri 21 Aug 2009</td>
<td></td>
</tr>
<tr>
<td>Week 3</td>
<td>Mon 24 Aug 2009 - Fri 28 Aug 2009</td>
<td></td>
</tr>
<tr>
<td>Week 4</td>
<td>Mon 31 Aug 2009 - Fri 04 Sep 2009</td>
<td></td>
</tr>
<tr>
<td>Week 5</td>
<td>Mon 07 Sep 2009 - Fri 11 Sep 2009</td>
<td></td>
</tr>
<tr>
<td>Week 6</td>
<td>Mon 14 Sep 2009 - Fri 18 Sep 2009</td>
<td></td>
</tr>
<tr>
<td>Recess Week</td>
<td>Sat 19 Sep 2009 - Sun 27 Sep 2009</td>
<td>1 week</td>
</tr>
<tr>
<td>Week 7</td>
<td>Mon 28 Sep 2009 - Fri 02 Oct 2009</td>
<td></td>
</tr>
<tr>
<td>Week 8</td>
<td>Mon 05 Oct 2009 - Fri 09 Oct 2009</td>
<td></td>
</tr>
<tr>
<td>Week 9</td>
<td>Mon 12 Oct 2009 - Fri 16 Oct 2009</td>
<td></td>
</tr>
<tr>
<td>Week 10</td>
<td>Mon 19 Oct 2009 - Fri 23 Oct 2009</td>
<td></td>
</tr>
<tr>
<td>Week 11</td>
<td>Mon 26 Oct 2009 - Fri 30 Oct 2009</td>
<td></td>
</tr>
<tr>
<td>Week 12</td>
<td>Mon 02 Nov 2009 - Fri 06 Nov 2009</td>
<td></td>
</tr>
<tr>
<td>Week 13</td>
<td>Mon 09 Nov 2009 - Fri 13 Nov 2009</td>
<td></td>
</tr>
<tr>
<td>Reading Week</td>
<td>Sat 14 Nov 2009 - Fri 20 Nov 2009</td>
<td>1 week</td>
</tr>
<tr>
<td>Examination</td>
<td>Sat 21 Nov 2009 - Sat 05 Dec 2009</td>
<td>2 weeks</td>
</tr>
</tbody>
</table>

### Data Analysis (You can attend on any date)

1. 18 August, Tuesday, 1-4pm, CSD lab 1 (S13-04-16)
2. 19 August, Wednesday, 9-12pm, CSD lab 1 (S13-04-16)
3. 19 August, Wednesday, 1-4pm, CSD lab 1 (S13-04-16)
4. 20 August, Thursday, 1-4pm, CSD lab 1 (S13-04-16)
5. 21 August, Friday, 1-4pm, CSD lab 1, (S13-04-16)

Every student has to submit an assignment on data analysis to level 1 Physics laboratory by **31 August (Monday) 5pm**.

---

### Data Analysis (You can attend on any date)

1. 18 August, Tuesday, 1-4pm, CSD lab 1 (S13-04-16)
2. 19 August, Wednesday, 9-12pm, CSD lab 1 (S13-04-16)
3. 19 August, Wednesday, 1-4pm, CSD lab 1 (S13-04-16)
4. 20 August, Thursday, 1-4pm, CSD lab 1 (S13-04-16)
5. 21 August, Friday, 1-4pm, CSD lab 1, (S13-04-16)

### Schedule for Practical - PC1221

<table>
<thead>
<tr>
<th>Week</th>
<th>Odd Week</th>
<th>Even Week</th>
<th>Odd Week</th>
<th>Even Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>(2), 3, 5, 7, 9, 11</td>
<td>(2), 4, 6, 8, 10, 12</td>
<td>(2), 3, 5, 7, 9, 11</td>
<td>(2), 4, 6, 8, 10, 12</td>
</tr>
<tr>
<td>Monday</td>
<td>9 - 12 nn</td>
<td>9 - 12 nn</td>
<td>1 - 4 pm</td>
<td>1 - 4 pm</td>
</tr>
<tr>
<td>Tuesday</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wednesday</td>
<td>SA1</td>
<td>SA5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thursday</td>
<td>SA2</td>
<td>SA6</td>
<td>SA3</td>
<td>SA7</td>
</tr>
<tr>
<td>Friday</td>
<td>SA4</td>
<td>SA8</td>
<td>SA9</td>
<td>SA10</td>
</tr>
</tbody>
</table>

Practical Venues: Block S12, 04-02 Level 1 Physics Lab
Schedule for **Tutorial - PC1221**

<table>
<thead>
<tr>
<th>Day</th>
<th>Even Week</th>
<th>Odd Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wednesday</td>
<td>ST2, ST6</td>
<td></td>
</tr>
<tr>
<td>Thursday</td>
<td></td>
<td>ST4, ST8</td>
</tr>
<tr>
<td>Friday</td>
<td>ST5, ST10</td>
<td></td>
</tr>
</tbody>
</table>

**Tutorial Venues (Do not go to the wrong place):**

ST1 - ST8 : Block S11-03-01 Physics Lab Instruction Room
ST9 - ST10: Block S13-04-14 CSD Lab 2

**Resources**

- **IVLE (Integrated Virtual Learning Environment):** http://ivle.nus.edu.sg
  You can post questions there for discussion. All students are encouraged to contribute their answers.
  (IVLE is solely for academic discussion purpose.)

**Expectations**

- Attend all lectures, labs and tutorials
- Participate in IVLE discussion at least twice a week

**Lectures**

- Spend 30 mins reading the textbook and lecture notes on the topics to be covered in each upcoming lecture.
- Spend 60 mins reading and practicing the questions in the textbook after the lecture.

**Tutorials**

- Prepared fully written answers for most of the questions at least one night before. You can be asked to show your solutions so please do your homework.

**Laboratory**

- Read the Lab scripts before your scheduled sessions
- Come with a spirit of wanting to learn
- **Plagiarism is a serious offence in all NUS modules**

**Course website**

- Regularly access course website for up-to-date materials
- Soft copy of lecturenotes will be uploaded **after** each lecture
Support Team at Physics Year-1 Lab

Mdm Pang Teng Jar
Lab In Charge

Mdm Cheong, Elaine

Mr Foong Chee Kong

Mdm Koh Siew Lee

Teaching Team

Mr. Lim Yen Kheng
Office: S12-02-12
Tel: (65)-6516-2625
Fax: (65)-6777-6126
Email: phylyk@nus.edu.sg
Tutor (except ST2 and ST9)

A/Prof Tay Seng Chuan
Lecturer for all, and Tutor for ST2 and ST9

Mr Kenneth Hong
Office: S13-04-03
Tel: (65)-6516-2631
Fax: (65)-6777-6126
Email: phyhcmk@nus.edu.sg
Lab Instructor (Assisted by Honours Year and Graduate Students)

End of Introduction

Any question?

Historical Overview

- Physics is a fundamental science
  - concerned with the basic principles of the Universe
  - foundation of other physical sciences
- Physics is divided into six major areas
  - Classical Mechanics
  - Relativity
  - Thermodynamics
  - Electromagnetism
  - Optics
  - Quantum Mechanics
Classical Physics

- Mechanics and electromagnetism are basic to all other branches of classical physics
- Classical physics developed before 1900
  - Our study will start with Classical Mechanics
    - Also called Newtonian Mechanics

Classical Physics, cont

Includes
- Mechanics
  - Major developments by Newton (1642 - 1727), and continuing through the latter part of the 19th century
- Thermodynamics
- Optics
- Electromagnetism
  - All of these were not developed until the latter part of the 19th century mainly because the apparatus was too crude or unavailable.

Modern Physics

- Began near the end of the 19th century
- Phenomena that could not be explained by classical physics, eg, when the speed of a particle is extremely fast (near speed of light)
- Includes theories of relativity (Albert Einstein, 1879-1955) and quantum mechanics

Classical Mechanics Today

- Still important in many disciplines, eg, bio-physics
- There is a wide range of phenomena that can be explained with classical mechanics, eg, traffic congestion along highways
- Many basic principles carry over into other phenomena and applications, eg, high speed computation, unmanned planetary explorations, manned moon landings, etc.
- Conservation Laws also apply directly to other areas such as in global warming, tidal wave etc.
Objective of Physics

- To find the limited number of fundamental laws that govern natural phenomena
- To use these laws to develop theories that can predict the results of future experiments
- Express the laws in the language of mathematics
- We want to put down the ideas in concrete form (in written words).

Theory and Experiments

- They should complement each other
- When a discrepancy occurs, theory may be modified, and usually not the other way around. We should not cheat in our experiment. It is also now a criminal offence to cheat in research work (misuse of public fund).

Embryo cloning cheat resigns in disgrace

By Roger Highfield Science Editor
Last Updated: 1:07am GMT 24/12/2005

The world's most successful cloning scientist, Prof Hwang Woo-suk, who was hailed as a superstar with "God's hand" in his native South Korea, has resigned in disgrace. The furore that erupted yesterday over how his team partly faked results will send shock waves around the scientific world, damage the image of biotechnology and cast a shadow over rival British efforts to develop the next generation of medicine.

Prof Hwang Woo-suk apologises to South Korea

Hwang made headlines last year when he unveiled the first cloned human embryo. This year he published an apparent tour de force, reporting the creation of more than 30 cloned human embryos and 11 lines of stem cells which could be grown into any of the 200 cell types found in the body.

The work marked the start of what many scientists believed would be a revolution, with stem cells being grown from patients to treat a vast range of diseases.

Pro-life groups condemned the research as "repugnant manipulation" and "trivialisation" of a human life. "Never cheat in our experiment!! No plagiarism!!

Theory and Experiments, cont

- Theory may apply to limited conditions only. It may not be able to explain all physical phenomena.
  - Example: Newtonian Mechanics is confined to objects traveling slowly with respect to the speed of light
- We should try to develop a more general theory. Why?
  A specific explanation to a particular case may not be applicable to other cases.
Quantities Used

- In mechanics, three basic quantities are used:
  - Length
  - Mass
  - Time
- We will also use derived quantities:
  - Derived quantities can be expressed in terms of basic quantities.

Standards of Quantities

- Standardized systems agreed upon by some authority, usually a governmental body.
- SI – Système International:
  - agreed to in 1960 by an international committee
  - SI system is used in this module
- Common denomination used is base 10. Why?

Length

- Units:
  - SI – meter, m
- Defined in terms of a meter – the distance traveled by light in a vacuum during a given time of $1/299792458$ second (announced in October 1983).

<table>
<thead>
<tr>
<th>Approximate Values of Some Measured Lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
</tr>
<tr>
<td>Distance from the Earth to the most remote known quasar</td>
</tr>
<tr>
<td>Distance from the Earth to the most remote normal galaxies</td>
</tr>
<tr>
<td>Distance from the Earth to the nearest large galaxy (M 31, the Andromeda galaxy)</td>
</tr>
<tr>
<td>Distance from the Sun to the nearest star (Proxima Centauri)</td>
</tr>
<tr>
<td>One lightyear</td>
</tr>
<tr>
<td>Mean orbit radius of the Earth about the Sun</td>
</tr>
<tr>
<td>Mean distance from the Earth to the Moon</td>
</tr>
<tr>
<td>Distance from the equator to the North Pole</td>
</tr>
<tr>
<td>Mean radius of the Earth</td>
</tr>
<tr>
<td>Typical altitude (above the surface) of a satellite orbiting the Earth</td>
</tr>
<tr>
<td>Length of a football field</td>
</tr>
</tbody>
</table>
Mass

- Units
  - SI - kilogram, kg
- Defined in terms of a kilogram, based on a specific cylinder made of platinum-iridium alloy kept at the International Bureau of Standards in France

Time

- Units
  - seconds, s
- Defined in terms of the oscillation of radiation from a cesium atom (stable for 20 million years)
  (Cesium is used to make atomic clock)

Table 1.2

<table>
<thead>
<tr>
<th>Objects</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observable Universe</td>
<td>~10^{52}</td>
</tr>
<tr>
<td>Milky Way Galaxy</td>
<td>~10^{32}</td>
</tr>
<tr>
<td>Sun</td>
<td>1.99 x 10^{30}</td>
</tr>
<tr>
<td>Earth</td>
<td>5.98 x 10^{24}</td>
</tr>
<tr>
<td>Moon</td>
<td>7.36 x 10^{22}</td>
</tr>
<tr>
<td>Shark</td>
<td>~10^{3}</td>
</tr>
<tr>
<td>Human</td>
<td>~10^{2}</td>
</tr>
<tr>
<td>Frog</td>
<td>~10^{-1}</td>
</tr>
<tr>
<td>Mosquito</td>
<td>~10^{-5}</td>
</tr>
<tr>
<td>Bacterium</td>
<td>~1 x 10^{-15}</td>
</tr>
<tr>
<td>Hydrogen Atom</td>
<td>1.67 x 10^{-27}</td>
</tr>
<tr>
<td>Electron</td>
<td>9.11 x 10^{-31}</td>
</tr>
</tbody>
</table>

~100 kg

Table 1.3

<table>
<thead>
<tr>
<th>Time Interval (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of the Universe</td>
</tr>
<tr>
<td>Age of the Earth</td>
</tr>
<tr>
<td>Average age of a college student</td>
</tr>
<tr>
<td>One year</td>
</tr>
<tr>
<td>One day (time interval for one revolution of the Earth about its axis)</td>
</tr>
<tr>
<td>One class period</td>
</tr>
<tr>
<td>Time interval between normal heartbeats</td>
</tr>
<tr>
<td>Period of audible sound waves</td>
</tr>
<tr>
<td>Period of typical radio waves</td>
</tr>
<tr>
<td>Period of vibration of an atom in a solid</td>
</tr>
<tr>
<td>Period of visible light waves</td>
</tr>
<tr>
<td>Duration of a nuclear collision</td>
</tr>
<tr>
<td>Time interval for light to cross a proton</td>
</tr>
</tbody>
</table>

6.3 x 10^{8} / (3600 x 24 x 365) = 19.98 years

Calculate the ages of your parents in seconds.
**Number Notation**

- When writing out numbers with many digits, it is recommended that you space them in groups of three.
  - No commas (comma is used in financial figure, eg: $45,000)
- Examples:
  - 25 100
  - 5.123 456 789 12

---

**Reasonableness of Results**

- When solving a problem, we need to check our answer to see if it seems reasonable. Eg: Your weight of 62.5345456 kg is an unnecessarily overloaded figure. Simply 62.5 kg will do!!

---

**Systems of Measurements, cont**

- US Customary
  - Length is measured in feet
  - Time is measured in seconds
  - Mass is measured in slugs

---

**Prefixes**

- The prefixes can be used with any base units
- They are multipliers of the base unit
- Examples:
  - 1 mm = 10^-3 m
  - 1 mg = 10^-3 g

---

**Table 1.4**

<table>
<thead>
<tr>
<th>Power</th>
<th>Prefix</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^-24</td>
<td>yocto</td>
<td>y</td>
</tr>
<tr>
<td>10^-21</td>
<td>zepto</td>
<td>z</td>
</tr>
<tr>
<td>10^-18</td>
<td>atto</td>
<td>a</td>
</tr>
<tr>
<td>10^-15</td>
<td>femto</td>
<td>f</td>
</tr>
<tr>
<td>10^-12</td>
<td>pico</td>
<td>p</td>
</tr>
<tr>
<td>10^-9</td>
<td>nano</td>
<td>n</td>
</tr>
<tr>
<td>10^-6</td>
<td>micro</td>
<td>μ</td>
</tr>
<tr>
<td>10^-3</td>
<td>milli</td>
<td>m</td>
</tr>
<tr>
<td>10^-2</td>
<td>centi</td>
<td>c</td>
</tr>
<tr>
<td>10^-1</td>
<td>deci</td>
<td>d</td>
</tr>
<tr>
<td>10^3</td>
<td>kilo</td>
<td>k</td>
</tr>
<tr>
<td>10^6</td>
<td>mega</td>
<td>M</td>
</tr>
<tr>
<td>10^9</td>
<td>giga</td>
<td>G</td>
</tr>
<tr>
<td>10^12</td>
<td>tera</td>
<td>T</td>
</tr>
<tr>
<td>10^15</td>
<td>peta</td>
<td>P</td>
</tr>
<tr>
<td>10^18</td>
<td>exa</td>
<td>E</td>
</tr>
<tr>
<td>10^21</td>
<td>zetta</td>
<td>Z</td>
</tr>
<tr>
<td>10^24</td>
<td>yotta</td>
<td>Y</td>
</tr>
</tbody>
</table>
Model Building

- A **model** is a system of physical components
  - Identify the components
  - Make predictions about the behavior of the system
    - The predictions will be based on interactions among the components and/or
    - Based on the interactions between the components and the environment
  - Model is evolving

**Model of Trigonometric Functions**

\[
\sin A = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{a}{h} \\
\cos A = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{b}{h} \\
\tan A = \frac{\text{opposite}}{\text{adjacent}} = \frac{a}{b} = \frac{\sin A}{\cos A}
\]

**Question:** A high fountain of water is located at the center of a circular pool as in Figure. Not wishing to get his feet wet, a student walks around the pool and measures its circumference to be 15.0 m. Next, the student stands at the edge of the pool and uses a protractor to gauge the angle of elevation of the top of the fountain to be 55.0°. How high is the fountain?

**Answer:**

\[
2\pi r = 15.0 \text{ m} \\
r = 2.39 \text{ m} \\
\frac{h}{r} = \tan 55.0° \\
h = (2.39 \text{ m}) \tan (55.0°) = 3.41 \text{ m}
\]

**Models of Matter**

- Some Greeks thought matter is made of atoms
- JJ Thomson (1897) found electrons and showed atoms had structure
- Rutherford (1911) discovered central nucleus surrounded by electrons
Models of Matter, cont

- Nucleus has structure, containing protons and neutrons
  - Number of protons gives atomic number
  - Total number of protons and neutrons gives mass number
- Protons and neutrons are made up of quarks

There are 6 types of quarks, named as up, down, strange, charmed, bottom and top.

- The up, charmed and top quarks have electric charges of +2/3 that of the proton.
- The down, strange, and bottom quarks have charges of -1/3 that of the proton.
- Each proton has 2 up quarks and 1 down quark, and each neutron has 2 down quark and 1 up quark.

Can you explain why each proton has +1 unit of charge, and neutron has no charge?

Modeling Technique

- Important technique is to build a model for a problem
  - Identify a system of physical components for the problem
  - Make predictions of the behavior of the system based on the interactions among the components and/or the components and the environment

Density

- Density is an example of a derived quantity
  - It is defined as mass per unit volume
    \[ \rho = \frac{m}{V} \]
  - Units are kg/m³
### Atomic Mass
- The atomic mass is the total number of protons and neutrons in the element.
- Can be measured in atomic mass units, $u$
  - $1 \text{u} = 1.6605387 \times 10^{-27} \text{ kg}$

### Basic Quantities and Their Dimension
- Dimension has a specific meaning - it denotes the physical nature of a quantity.
- Dimensions are denoted with square brackets:
  - Length $[L]$
  - Mass $[M]$
  - Time $[T]$

### Dimensional Analysis
- Technique to check the correctness of an equation or to assist in deriving an equation.
- Dimensions (length, mass, time, combinations) can be treated as algebraic quantities:
  - add, subtract, multiply, divide
- Both sides of equation must have the same dimensions.
Dimensional Analysis, cont.

- Cannot give numerical factors: this is its limitation
- Dimensions of some common quantities are given below

<table>
<thead>
<tr>
<th>Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>The symbol used in an equation is not necessarily the symbol used for its dimension</td>
</tr>
<tr>
<td>Eg: $x = \nu \times t$, i.e., distance = velocity $\times$ time</td>
</tr>
<tr>
<td>Some quantities have one symbol used consistently</td>
</tr>
<tr>
<td>For example, time is $t$</td>
</tr>
<tr>
<td>Some quantities have many symbols used, depending upon the specific situation. For example, lengths may be $x, y, z, r, d, h$, etc.</td>
</tr>
</tbody>
</table>

Table 1.6

<table>
<thead>
<tr>
<th>Units of Area, Volume, Velocity, Speed, and Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>SI</td>
</tr>
<tr>
<td>U.S. customary</td>
</tr>
</tbody>
</table>

Dimensional Analysis, example

- Given the equation: $x = \frac{1}{2} at^2$, where $a$ is acceleration ($\nu/t$, i.e., (L/T)/T), $t$ is time, and $x$ is distance
- Check dimensions on each side:
  \[ L = \frac{L}{T^2} \times T = L \]
- The T$^2$'s cancel each other, leaving L for the dimensions of each side
  - The equation is dimensionally correct
  - There are no dimensions for the constant $\frac{1}{2}$.

Example. Newton’s law of universal gravitation is represented by

\[ F = \frac{G M m}{r^2} \]

Here $F$ is the gravitational force exerted by one small object on another, $M$ and $m$ are the masses of the objects, and $r$ is a distance. Force has the SI units kg·m/s$^2$. What are the SI units of the proportionality constant $G$?

Answer: Inserting the proper units for everything except $G$,\n\[ \frac{[m]}{[kg]} \times \frac{[kg \cdot m]}{[s^2]} = \frac{[kg]}{[m]} \times \frac{[m]}{[kg]} \]

Multiply both sides by $[m]^2$ and divide by $[kg]^2$; the units of $G$ are $\frac{m^3}{kg \cdot s^2}$. 

\[ G \]

53

54

55

56
**Question.** If an equation is dimensionally correct, does it always mean that the equation is correct?

**Answer:**

If an equation is dimensionally correct, it does **not** always mean that the equation is correct.

For an equation to be correct, it must first be dimensionally correct.

---

**Conversion of Units**

- When units are not consistent, you may need to convert them to appropriate ones.
- Units can be treated like algebraic quantities that can cancel each other.
- See the inside of the back cover for an extensive list of conversion factors, e.g.,
  - 1 in. = 2.54 cm,
  - 1 slug = 14.59 kg,
  - 1 gal = 3.786 L, etc.

---

**Conversion**

- Always include units for every quantity, you can carry the units through the entire calculation.
- Multiply original value by a ratio equal to one.
- Example: $15.0 \text{ in} = ? \text{ cm}$

\[
15.0 \text{ in} \left( \frac{2.54 \text{ cm}}{1 \text{ in}} \right) = 38.1 \text{ cm}
\]

---

**Cross Multiplying Reasoning**

Example

\[
1 \text{ in} = 2.54 \text{ cm} \\
15 \text{ in} = x \text{ cm}
\]

\[
1 \times x = 2.54 \times 15 \\
x = 38.1 \text{ cm}
\]
Uncertainty in Measurements

- There is uncertainty in every measurement -- this uncertainty carries over through the calculations
  - need a technique to account for this uncertainty
- We will use rules for significant figures to approximate the uncertainty in results of calculations

Significant Figures

- A significant figure is one that is reliably known
- Zeros may or may not be significant
  - Eg, How accurate is 1500 kg in a measurement? Is the accuracy up to 1 kg, 10 kg, or 100 kg?
  - Those zeros used to position the decimal point are not significant. Eg, 0.00075
  - To remove ambiguity, use scientific notation
- In a measurement, the significant figures include the first estimated digit

Significant Figures, examples

- 0.0075 m has 2 significant figures
  - The leading zeros are placeholders only
  - Can write in scientific notation to show more clearly: $7.5 \times 10^{-3} \text{ m}$ for 2 significant figures
- 10.0 m has 3 significant figures
  - The decimal point gives information about the reliability of the measurement
- 1500 m is ambiguous
  - Use $1.5 \times 10^3 \text{ m}$ for 2 significant figures
  - Use $1.50 \times 10^3 \text{ m}$ for 3 significant figures
  - Use $1.500 \times 10^3 \text{ m}$ for 4 significant figures
  - On the safe side, we usually treat the number as $1.5 \times 10^3$ for 2 significant figures if there is no further information

Operations with Significant Figures – Multiplying or Dividing

- When multiplying or dividing, the number of significant figures in the final answer is the same as the number of significant figures in the quantity having the lowest number of significant figures.
- Example: $25.57 \text{ m} \times 2.45 \text{ m} = 62.6 \text{ m}^2$ (not 62.6465)
  - This is because 2.45 m limits our result to 3 significant figures
**Operations with Significant Figures – Adding or Subtracting**

- When adding or subtracting, the number of decimal places in the result should equal the smallest number of decimal places in any term in the sum.
- Example: $135 \text{ cm} + 3.251 \text{ cm} = 138 \text{ cm}$ (not $138.251$ as $135$ has no decimal place)
- The $135$ cm limits your answer to the units decimal value

**Operations With Significant Figures – Summary**

- The rule for addition and subtraction are different than the rule for multiplication and division of measured data.
- For adding and subtracting, the number of decimal places is the important consideration, eg, $101.3 + 3.624 = 104.9$ (not $104.924$ because $101.3$ has $1$ decimal place only), $123+5.35 = 128$ (not $128.35$ because $123$ has no decimal place), $1.001 + 0.0003 = 1.004$, $1.002-0.998 = 0.004$ (1 significant digit).
- For multiplying and dividing, the number of significant figures is the important consideration, eg $8912.458 \times 0.72 = 6400$ (not $6416.96976$ because $0.72$ has $2$ significant figures), $98.76/1.21 = 81.6$ (not $81.6198347$ because $1.21$ has $3$ significant figures.)

**Rounding (Proposed New Model)**

- Rounding can worsen the accuracy of calculation (the more rounded figures you use the worse is the accuracy) but why are we doing it. One of the reasons is that computation can be faster with less number of digits. So we have to come up with a scheme to manage the inaccuracy, i.e., to make the inaccuracy not too inaccurate. Our scheme is as follows:
  1. Last retained digit is increased by 1 if the last digit dropped is greater than 5, eg: round $99.47$ will give $99.5$.
  2. Last retained digit remains as it is if the last digit dropped is less than 5, eg: round $99.42$ will give $99.4$.
  3. If the last digit dropped is equal to 5, the retained digit should be rounded to the nearest even number, eg: round $99.45$ will give $99.4$, and round $99.55$ will give $99.6$. We hope by doing so in the long run we can reduce the accumulation of arithmetic inaccuracy (the terms level out by themselves in the long arithmetic process).
  4. Saving rounding until the final result will help eliminate accumulation of errors, i.e., don't do rounding during the intermediate steps.

This is the procedure we use and is different from what we have learnt in secondary school.

**Notes:**

- What is taught here is a proposed model.
- This does not mean that all calculations will have to adopt the new model. For example, the Microsoft Excel Software does not adopt the proposed new model.
- When the accuracy of data is not mentioned, we assume that the data is absolutely and infinitely accurate thus the rules mentioned in this chapter do not apply. E.g., $12.34$ is treated as $12.340000000000000$...
- We apply the rules only when its application is instructed, i.e., when you are told to do so.
- In any models, rounding should be done only in the last step. All intermediate steps and all intermediate answers should not be rounded and all digits must be kept.