Units and Dimensions

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Outline

- **1-Introduction to Physics.**
- **2-What are units and dimensions in physics.**
- **3-Characteristics of Standard Unit.**
- **4-Classification of Units.**
- **5- Classification of Units.**
- **6- Light-Year as an application with other examples**
- **6- Overview of the SI quantities and units.**
- **7- In Conclusion**

Objectives

1- indicate the important dimensionless groups of variables, reduce the model to a minimal form, and make it easy to assess asymptotic behavior of the system.

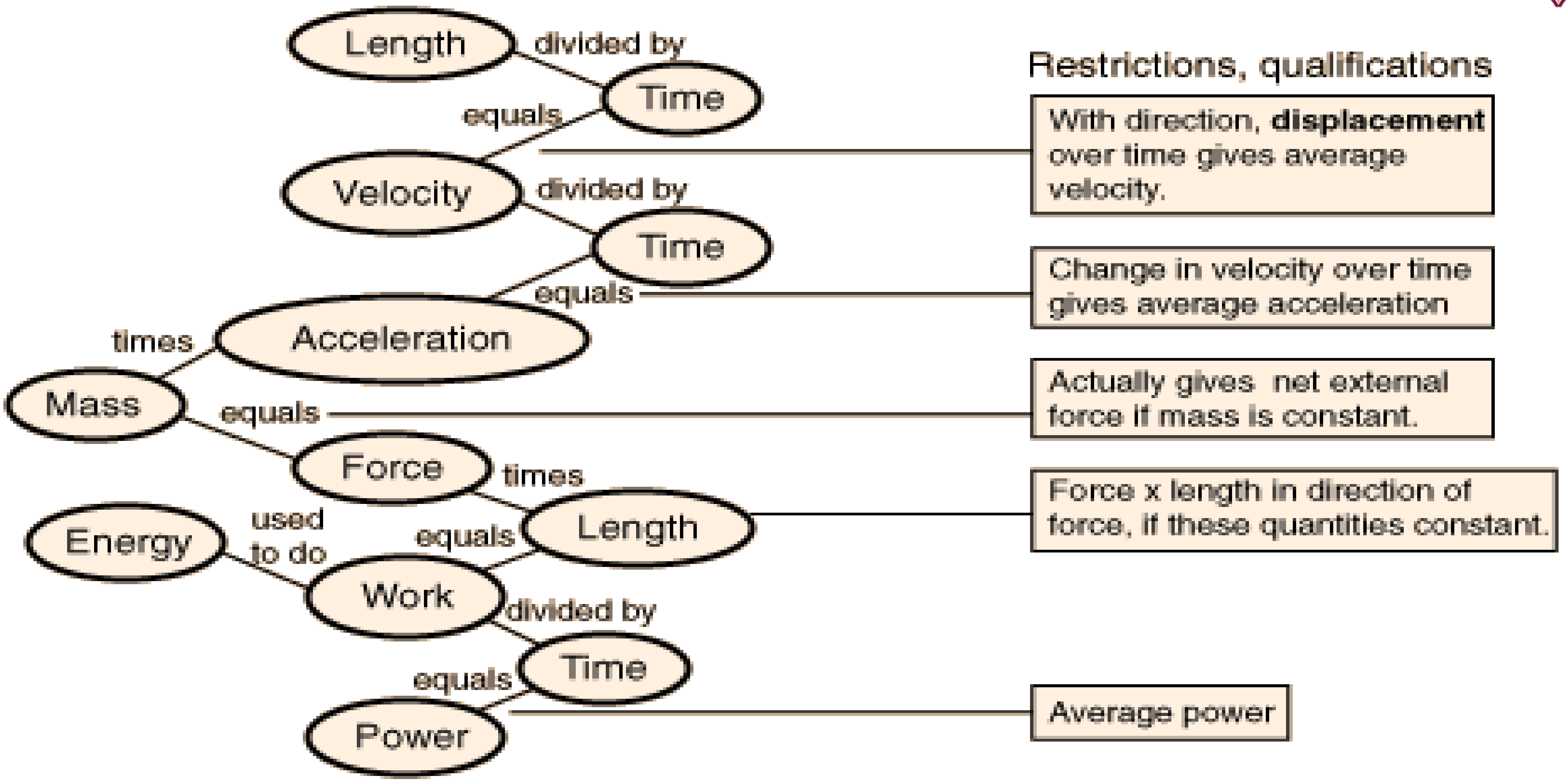
2-determine whether equations are dimensionally homogeneous.

3-check the units of a solution they have reached and verify that they are correct. correct.

4- use dimensional analysis to determine the appropriate units for an unknown q quantity in an equation.

5- apply dimensional analysis to predict formulas which connect particular variables in given circumstances

The Chain of Mechanical Quantities



Introduction to Physics

Physics is the branch of science, which deals with the study of nature and properties of matter and energy. The subject matter of physics includes heat, light, sound, electricity, magnetism and the structure of atoms. For designing a law of physics, a scientific method is followed which includes the verifications with experiments. The physics, attempts are made to measure the quantities with the best accuracy. Thus, Physics can also be defined as science of measurement.

Physical Quantities: All quantities in terms of which laws of physics can be expressed and which can be measured are called Physical Quantities. For example; Distance, Speed, Mass, Force etc.

What are units and dimensions in physics

Units and dimensions in physics are two sides of a coin. They go together because a unit is nothing without a dimension and vice versa. Units are the describing part for any physical quantity because it gives us the exact measurement of that physical quantity so that everyone can understand and relate to the actual measurement of the quantity.

The quantity used as standard for measurement is called unit.

For example, when we say that length of the class room is 8 meter.

We compare the length of class room with standard quantity of length called meter. Length of class room = 8 meter

Q = nu

Physical Quantity = Numerical value × unit

Q = Physical Quantity

n = Numerical value

u = Standard unit e.g. Mass of stool = 15 kg Mass = Physical quantity 15 = Numerical value Kg = Standard unit Means mass of stool is 15 times of known quantity i.e. Kg

The three base dimensions in mechanics are length, mass, time, temperature

Characteristics of Standard Unit:

A unit selected for measuring a physical quantity should have the following properties

(i) It should be well defined i.e. its concept should be clear.

(ii) It should not change with change in physical conditions like temperature, pressure, stress etc..

(iii) It should be suitable in size; neither too large nor too small.

(iv) It should not change with place or time.

(v) It should be reproducible.

(vi) It should be internationally accepted.

Classification of Units:

Units can be classified into two categories. • Fundamental • Derived

Fundamental Quantity:

The quantity which is independent of other physical quantities. In mechanics, mass, length and time are called fundamental quantities. Units of these fundamental physical quantities are called Fundamental units.

e.g. Fundamental Physical Quantity	Fundamental unit
Mass	Kg, Gram, Pound
Length	Meter, Centimeter, Foot
Time	Second

Derived Quantity: The quantity which is derived from the fundamental quantities e.g. area is a derived quantity.

Area = Length × Breadth

= Length × Length

= $(\text{Length})^2$

Speed = Distance / Time = Length / Time

The units for derived quantities are called Derived Units.

Systems of Units : CGS, FPS, MKS, SI For measurement of physical quantities, the following systems are commonly used:-

(i) C.G.S system: In this system, the unit of length is centimeter, the unit of mass is gram and the unit of time is second.

(ii) F.P.S system: In this system, the unit of length is foot, the unit of mass is pound and the unit of time is second.

(iii) M.K.S: In this system, the unit of length is meter, unit of mass is kg and the unit of time is second.

(iv) S.I System: This system is an improved and extended version of M.K.S system of units. It is called **international system of unit.**

Light-Year: Astronomical distances are sometimes described in terms of light-years (ly). A light-year is the distance that light will travel in one year (yr). How far in meters does light travel in one year ?

Using the relationship distance = (speed of light) · (time), one light year corresponds to a distance. Because the speed of light is given in terms of meters per second, we need to know how many seconds are in a year. We can accomplish this by converting units. We know that 1 year = 365.25 days, 1 day = 24 hours, 1 hour = 60 minutes, 1 minute = 60 seconds Putting this together we find that the number of seconds in a year is 1 year =(365.25 day) (24 hours /1day) (60 min 1 hour) (60 s /1min) = 31,557,600 s. The distance that light travels in a one year is

1 ly = (299,792,458 m/ 1s) (31,557,600 s /1 yr) (1 yr) = **9.461× 1015 m**

Table 1.1.11.1.1: Overview of the SI quantities and units, and the physical constants they are (or are proposed to be) based on.

quantity	Symbol	Unit	symbol	based on
length	L	meter	m	speed of light
time	T	second	s	cesium atom oscillation
mass	M	kilogram	kg	Planck's constant[1]
Current	I	Ampere	A	electron charge
Temperature	T	Kelvin	K	Boltzmann's constant
Luminosity	J	candela	cd	monochromatic radiation
particle count	N	mole	mol	Avogadro's constant

We will encounter only three different basic quantities, which have the dimensions of length (L), time (T), and mass (M). Thanks to the Napoleonic conquest of Europe in the early 1800s, we have a basic unit for each of these: meters (m) for length, seconds (s) for time, and kilograms (kg) for mass. Although we won't encounter them here, the standard system of units (called the System International, or SI) has four more of these basic pairs: (electric) current I, measured in Amperes (A), temperature T, measured in Kelvin (K), luminosity J, measured in candelas (cd), and 'amount of stuff', measured in moles (mole), From the seven basic quantities in the SI, all others can be derived. For example, speed is defined as the distance traveled (length) divided by the time it took, so speed has the dimension of **L/T** and is measured in units of m/s. Note that in order to be able to compare two quantities, they must have the same dimension . This simple observation has an important consequence: in any physics equation, the dimensions on both sides of the equality sign always have to be the same.

The Importance of Dimensions and Units

The importance of dimensions and units can be seen by dimensional analysis. The characteristics of physical quantities are described by the dimensions of base quantities and their combinations. Dimensional analysis can be used to recheck the equations for dimensional consistency, deduce relationships between distinct physical amounts, etc.

A dimensionally consistent equation must not be perfect or correct, whereas a dimensionally incorrect or inconsistent equation must be wrong.

Dimensional analysis has a wide range of applications.

To change a physical quantity’s value from one standard to another.

To ensure that a particular relationship is correct.

To come up with a relationship between different physical quantities.

In Conclusion

Units and dimensions are the building backbone of entire mechanical physics. If there were no units and dimensions in physics, there would have been no tool to accurately measure and use those measurements of the physical quantities to deduce the laws. We cannot imagine the importance of units and dimensions in this subject. You learned what units and dimensions in physics, and what is the importance of dimensions and units.

Dimensional Analysis There are many phenomena in nature that can be explained by simple relationships between the observed phenomena. Such as: (Period of a Pendulum), Consider a simple pendulum consisting of a massive bob suspended from a fixed point by a string. Let **T** denote the time (period of the pendulum) that it takes the bob to complete one cycle of oscillation. How does the period of the simple pendulum depend on the quantities that define the pendulum and the quantities that determine the motion? Solution: What possible quantities are involved? The length of the pendulum **l** , the mass of the pendulum bob **m**, the gravitational acceleration **g** , and the angular amplitude of the bob **θ0** are all possible quantities that may enter into a relationship for the period of the swing. Have we included every possible quantity? We can never be sure but let's first work with this set and if we need more than we will have to think harder! Our problem is then to find a function **f** such that **T = f (l,m,g,θ0)**

We first make a list of the dimensions of our quantities as shown in Table 1. Choose the set: mass, length, and time, to use as the base dimensions

We first make a list of the dimensions of our quantities as shown in Table 13. Choose the set: mass, length, and time , to use as the base dimensions

Dimensions of quantities that may describe the period of pendulum

Name of Quantity	Symbol	Dimensional Formula
Time of swing	t	T
Length of pendulum	l	L
Mass of pendulum	m	M
Gravitational acceleration	g	L ·T-2
Angular amplitude of swing	θ0	No dimension

Our first observation is that the mass of the bob cannot enter into our relationship, as our final quantity has no dimensions of mass and no other quantity can remove the dimension of the pendulum mass. Let's focus on the length of the string and the gravitational acceleration. In order to eliminate length, these quantities must divide each other in the above expression for T must divide each other. If we choose the combination l / g , the dimensions are

dim[l / g] = length length/(time) 2 = (time) 2

It appears that the time of swing is proportional to the square root of this ratio. We have an argument that works for our choice of constants, which depend on

Because the angular amplitude θ_0 is dimensionless, it may or may not appear. We can account for this by introducing some function $y(\theta_0)$ into our relationship, which is beyond the limits of this type of analysis. Then the time of swing is

$$T = y(\theta_0)\left(\frac{l}{g}\right)^{1/2} .$$

We shall discover later on that $y(\theta_0)$ is nearly independent of the angular amplitude θ_0 for very small amplitudes and is equal to $y(\theta_0) = 2\pi$,

$$T = 2\pi\left(\frac{l}{g}\right)^{1/2}$$

Dimensional formula for

$$\frac{1}{2}mv^2 = [\mathrm{M}][\mathrm{LT}^{-1}]^2 = [\mathrm{ML}^2\mathrm{T}^{-2}]$$

Dimensional formula for

$$mgh = [\mathrm{M}][\mathrm{LT}^{-2}][\mathrm{L}] = [\mathrm{ML}^2\mathrm{T}^{-2}]$$

$$[\mathrm{ML}^2\mathrm{T}^{-2}] = [\mathrm{ML}^2\mathrm{T}^{-2}]$$

Dimensional Analysis Problem Solving

How many yards are in 52 feet?

• Begin with what you have.	**52 ft.**
• Determine what you want.	**? yards**
	1 yard = 3 ft
• Create a Conversion Factor equal to 1, comparing what you have to what you want.	$\frac{1 \text{ yard}}{3 \text{ feet}}$ or $\frac{3 \text{ feet}}{1 \text{ yard}}$
• Set up the math with the conversion factor fraction multiplying to cancel the unit you have to convert to the unit desired.	$52 \text{ ft.} \times \frac{1 \text{ yard}}{3 \text{ ft.}}$
• Cancel the units	$52 \cancel{\text{ft.}} \times \frac{1 \text{ yard}}{3 \cancel{\text{ft.}}}$
• Calculate the answer.	**17.33 yds.**

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Extend Page

Recording...

Table 1.11 Dimensional Formula

Physical quantity	Expression	Dimensional formula
Area	length × breadth	$[L^2]$
Volume	Area × height	$[L^3]$
Density	mass / volume	$[ML^{-3}]$
Velocity	displacement/time	$[LT^{-1}]$
Acceleration	velocity / time	$[LT^{-2}]$
Momentum	mass × velocity	$[MLT^{-1}]$
Force	mass × acceleration	$[MLT^{-2}]$
Work	force × distance	$[ML^2T^{-2}]$
Power	work / time	$[ML^2T^{-3}]$
Energy	Work	$[ML^2T^{-2}]$
Impulse	force × time	$[MLT^{-1}]$
Radius of gyration	Distance	$[L]$
Pressure (or) stress	force / area	$[ML^{-1}T^{-2}]$
Surface tension	force / length	$[MT^{-2}]$
Frequency	1 / time period	$[T^{-1}]$
Moment of Inertia	mass × (distance)^2	$[ML^2]$
Moment of force (or torque)	force × distance	$[ML^2T^{-2}]$
Angular velocity	angular displacement / time	$[T^{-1}]$
Angular acceleration	angular velocity / time	$[T^{-2}]$
Angular momentum	linear momentum × distance	$[ML^2T^{-1}]$
Co-efficient of Elasticity	stress/strain	$[ML^{-1}T^{-2}]$
Co-efficient of viscosity	(force × distance) / (area × velocity)	$[ML^{-1}T^{-1}]$
Surface energy	work / area	$[MT^{-2}]$
Heat capacity	heat energy / temperature	$[ML^2T^{-2}K^{-1}]$
Charge	current × time	$[AT]$
Magnetic induction	force / (current × length)	$[MT^{-2}A^{-1}]$
Force constant	force / displacement	$[MT^{-2}]$
Gravitational constant	[force × (distance)^2] / (mass)^2	$[M^{-1}L^3T^{-2}]$
Planck's constant	energy / frequency	$[ML^2T^{-1}]$
Faraday constant	avogadro constant × elementary charge	$[AT\ mol^{-1}]$
Boltzmann constant	energy / temperature	$[ML^2\ T^{-2}\ K^{-1}]$

Dimensions of Some Common Mechanical Quantities

M ≡ mass, L ≡ length , T ≡ time Quantity Dimension MKS unit Angle dimensionless Dimensionless = radian Solid Angle dimensionless Dimensionless = sterradian Area L2 m2 Volume L3 m3 Frequency T-1 s −1 = hertz = Hz Velocity L ·T-1 m ·s −1 Acceleration L ·T-2 m ·s −2 Angular Velocity T-1 rad ·s −1 Angular Acceleration T-2 rad ·s −2 Density M · L-3 kg ·m−3 Momentum M · L ·T-1 kg ·m ·s −1 Angular Momentum M · L2 ·T-1 kg ·m2 ·s −1

References

1- Timon Idema Delft, 2023, MECHANICS AND RELATIVITY: - University of Technology