GENERAL PHYSICS 1 (3 UNITS)

PHY101

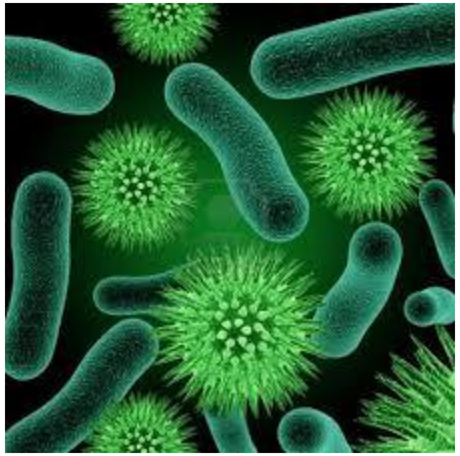
Dr. Odo Ayodele

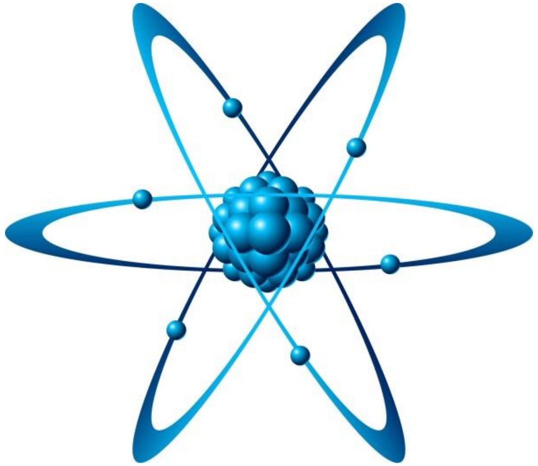
Course Synopsis

Course Lecturer	**Topics to be covered**	**Week**
ODO E.A. (DR.)	Units and dimension, standard and units, Unit consistency and conversions	1
OLUBOSEDE O. (DR.)	Kinematics; `displacement, Time, and average velocity	2
HAMMED O.S. DR)	Instantaneous velocity, average acceleration, motion with constant acceleration, freely falling bodies	3
OKETAYO O.O. (DR)	Position and velocity vector, acceleration vector, projectile motion, motion in a circle and relative velocity	4
IGBOAMA W.N. (DR)	Vectors: units vectors, addition vectors, products vectors. Fundamental Laws of Mechanics; forces and interaction,	5
OLUWADARE O. J.	Newton's laws of motion, mass and weight. Statics and dynamics: application of Newton's laws	6
FAREMI ABASS AKANDE	Dynamics of particles, frictional forces dynamics of circular motion.	7
EHIABHILI JOHN C.	Galilean invariance; Universal gravitational;	8
IBIYEMI A.A.	Work and energy; Rotational dynamics and angular momentum	9
ILYAS A.	Conservation laws.	10
ABE Oladipo	Space and Time, frame of reference, Invariance of physical law, relativity of simultaneity	11
Mrs EZE Chioma	Relativity of time interval, relativity of length	11

Units and dimension

Physics is based on measurement of physical quantities





1 nanometre =1.0 × 10^{-9} m

1 light year =9.4×10^{15} m

Examples are: length, mass, time, electric current, magnetic field, temperature, pressure ...

All physical quantities have dimensions: dimensions are basic types of quantities that can be measured or computed.

Dimension

– A physical entity that can be measured

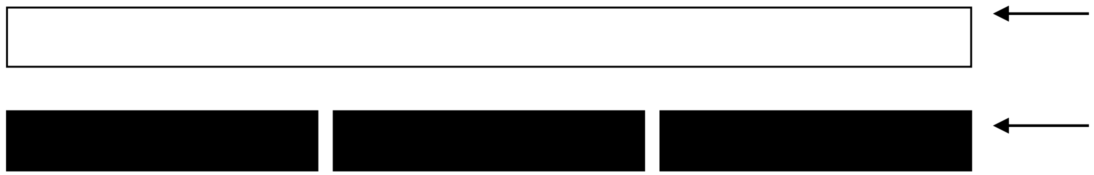
Basic Dimensions and Units

These quantities are the basic dimensions:

Length	[L]
Mass	[M]
Time	[T]

If we are to report the results of a measurement to someone who wishes to reproduce this measurement, a standard must be defined.

How long is the rod?



Rod of unknown length

Reference:
Three rods of 1-m length

The unknown rod is 3 m long.

A unit is a standard amount of a dimensional quantity.

Unit

– Quantitative magnitude of a dimension

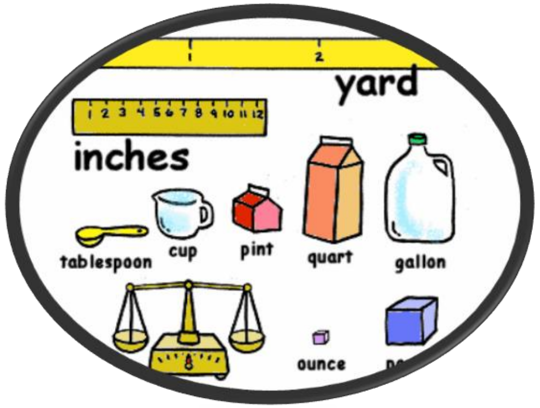
Units by themselves don’t make sense.

Numbers by themselves don’t make sense.

To make sense, all measurements need both . . .

A **Number**

a **Unit!**



The International System of Units (SI)

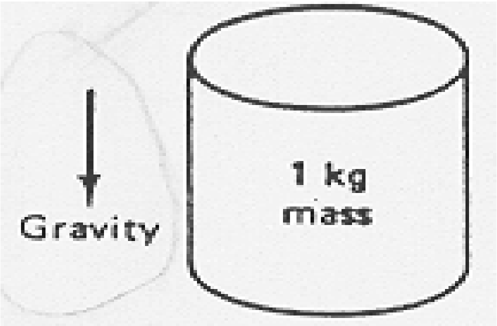
Fundamental Dimension	Base Unit
length [L]	meter (m)
mass [M]	kilogram (kg)
time [T]	second (s)
electric current [A]	ampere (A)
absolute temperature [θ]	kelvin (K)
luminous intensity [I]	candela (cd)
amount of substance [n]	mole (mol)

The International System of Units (SI)

Supplementary Dimension	Base Unit
plane angle	radian (rad)
solid angle	steradian (sr)

Fundamental Units (SI)

Mass: “a cylinder of platinum-iridium
(kilogram) alloy maintained under vacuum
conditions by the International
Bureau of Weights and
Measures in Paris”



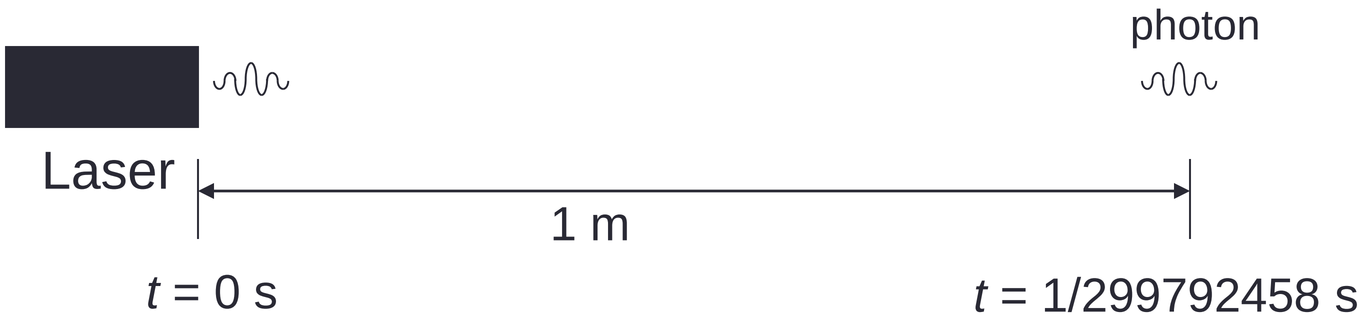
Fundamental Units (SI)

Time: (second)

"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-113 atom"

Fundamental Units (SI)

Length or Distance: (meter)	“the length of the path traveled by light in vacuum during a time interval of 1/299792458 seconds”

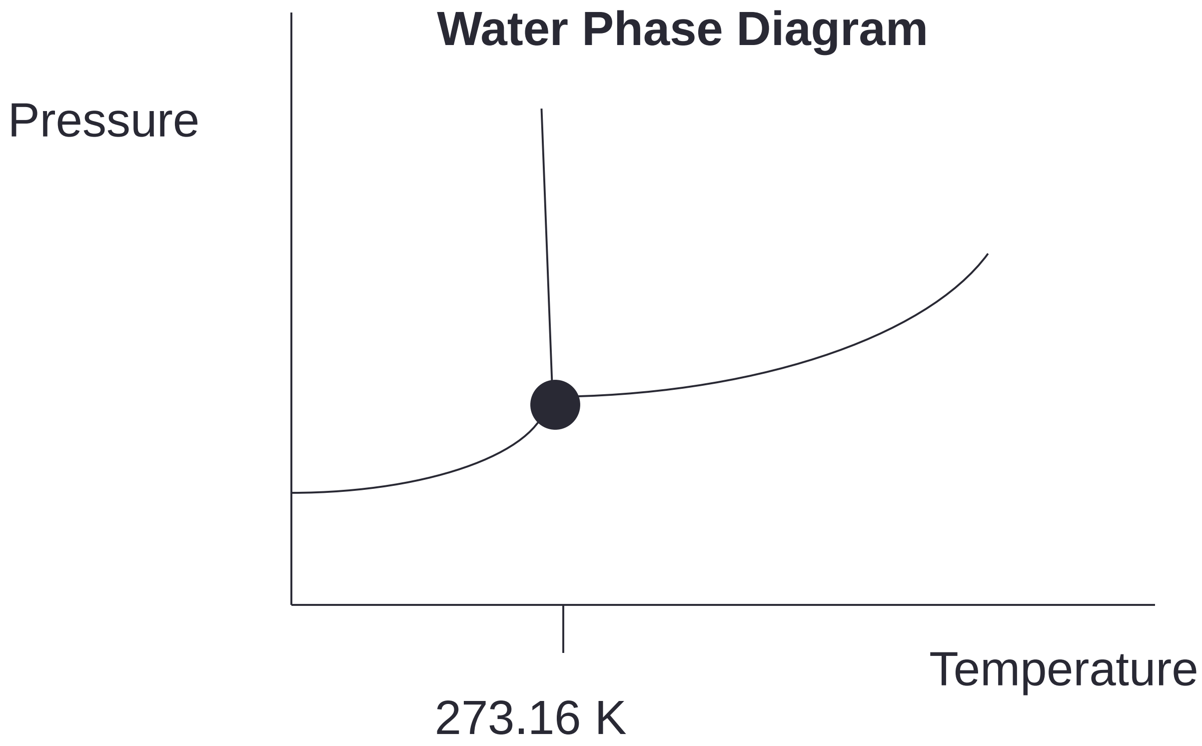


Fundamental Units (SI)

Electric Current: (ampere)	“that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed one meter apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newtons per meter of length”

Fundamental Units (SI)

Temperature: (kelvin)	The kelvin unit is 1/273.16 of the temperature interval from absolute zero to the triple point of water.



Fundamental Units (SI)

AMOUNT OF SUBSTANCE: (mole)	"the amount of a substance that contains as many elementary entities as there are atoms in 0.012 kilograms of carbon 12"

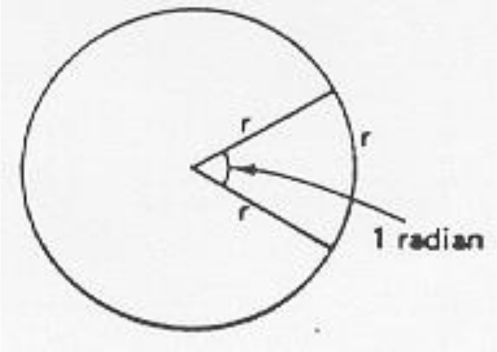
Fundamental Units (SI)

LIGHT OR LUMINOUS INTENSITY: (candela)

"the candela is the luminous intensity of a source that emits monochromatic radiation of frequency 540 × 10^{12} Hz and that has a radiant intensity of 1/683 watt per steradian."

Supplementary Units (SI)

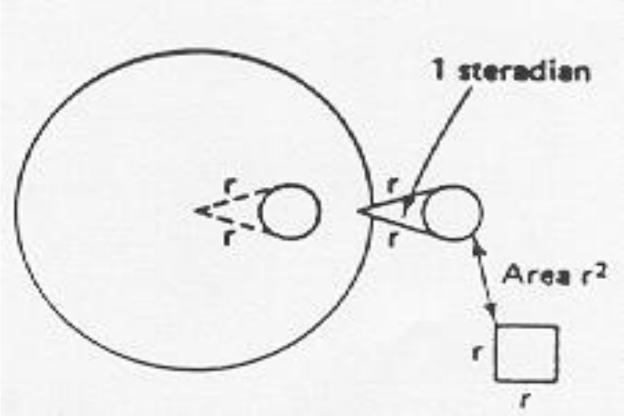
PLANE ANGLE: (radian)	"the plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius:



Supplementary Units (SI)

SOLID ANGLE: (steradian)

"the solid angle which, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere"



Derived Units

Other physical quantities are defined in terms of these base quantities:

- [velocity] = [length]/[time] = [L]/[T]
- [volume]=$[length]^3$=$[L]^3$
- [density]=[mass]/[volume]=[M]/$[L]^3$
- [force] = [mass][length] /$[time]^2$ = [M][L]/$[T]^2$

The International System of Units (SI)

Prefix	Decimal Multiplier	Symbol
nano	10^{-9}	n
micro	10^{-6}	μ
milli	10^{-3}	m
centi	10^{-2}	c
deci	10^{-1}	d
deka	10^{+1}	da
hecto	10^{+2}	h
kilo	10^{+3}	k
mega	10^{+6}	M
giga	10^{+9}	G

How do dimensions behave in mathematical formulae?

Rule 1 - All terms that are added or subtracted must have same dimensions

$$D = A + B - C$$

All have identical dimensions

How do dimensions behave in mathematical formulae?

Rule 2 - Dimensions obey rules of multiplication and division

$$D = \frac{AB}{C} = \frac{\left(\frac{[\mathrm{M}]}{[\mathrm{T}^2]}\right)\left(\frac{[\mathrm{T}^2]}{[\mathrm{L}]}\right)}{\left(\frac{[\mathrm{M}]}{[\mathrm{L}^2]}\right)} = [\mathrm{L}]$$

How do dimensions behave in mathematical formulae?

Rule 3 - In scientific equations, the arguments of "transcendental functions" must be dimensionless.

$$A = \ln(x) \qquad C = \sin(x)$$

$$B = \exp(x) \qquad D = 3^x$$

x must be dimensionless

Exception - In engineering correlations, the argument may have dimensions

Transcendental Function - Cannot be given by algebraic expressions consisting only of the argument and constants. Requires an infinite series

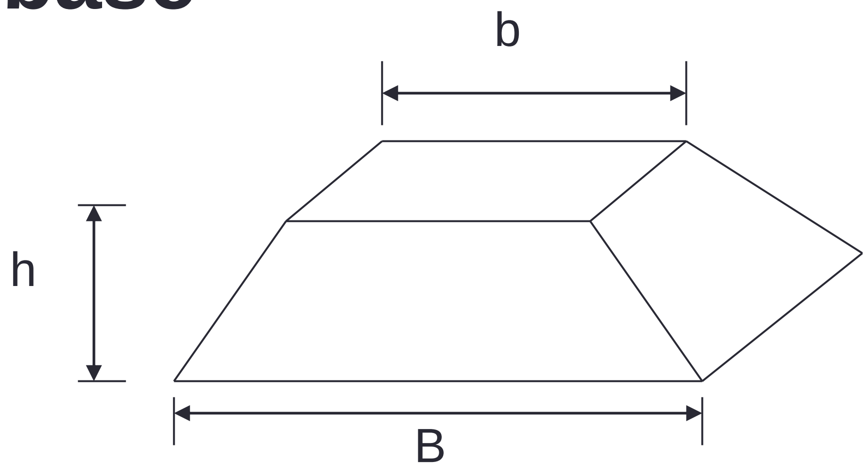
$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

Dimensionally Homogeneous Equations

An equation is said to be ***dimensionally homogeneous*** if the dimensions on both sides of the equal sign are the same.

Dimensionally Homogeneous Equations

Volume of the frustrum of a right pyramid with a square base



$$V = \frac{h}{3}\left(B^2 + Bb + b^2\right)$$

$$\left[L^3\right] = \left[\frac{L}{1}\right]\left(\left[L^2\right] + \left[L^2\right] + \left[L^2\right]\right) = \left[L^3\right].$$

Dimensional Analysis

Dimensions & units can be treated algebraically.

Variable from Eq.	x	m	t	$v=(x_f-x_i)/t$	$a=(v_f-v_i)/t$
dimension	L	M	T	L/T	L/T^2

Dimensional Analysis

Checking equations with dimensional analysis:

$$x_f - x_i = v_i t + \frac{1}{2} a t^2$$

L

(L/T)T=L

$(L/T^2)T^2=L$

- Each term must have same dimension
- Two variables can not be added if dimensions are different
- Multiplying variables is always fine
- Numbers (e.g. 1/2 or π) are dimensionless

Example 1.1

Check the equation for dimensional consistency:

$$mgh = \frac{mc^2}{\sqrt{1-(v/c)^2}} - mc^2$$

Here, *m* is a mass, g is an acceleration,
c is a velocity, *h* is a length

Example 1.2

Consider the equation:

$$m\frac{v^2}{r} = G\frac{Mm}{r^2}$$

Where *m* and *M* are masses, *r* is a radius and *v* is a velocity.
What are the dimensions of *G* ?

$L^3/(MT^2)$

Example 1.3

Given “x” has dimensions of distance, “u” has dimensions of velocity, “m” has dimensions of mass and “g” has dimensions of acceleration.

Is this equation dimensionally valid?

$$x = \frac{(4/3)ut}{1 - (2gt^2/x)}$$

Yes

Is this equation dimensionally valid?

$$x = \frac{vt}{1 - mgt^2}$$

No

Units vs. Dimensions

- Dimensions: L, T, M, L/T …
- Units: m, mm, cm, kg, g, mg, s, hr, years …
- When equation is all algebra: check dimensions
- When numbers are inserted: check units
- Units obey same rules as dimensions:
  Never add terms with different units
- Angles are dimensionless but have units (degrees or radians)
- In physics sin(Y) or cos(Y) never occur unless Y is dimensionless

Example 1.3

Grandma traveled 27 minutes at 44 m/s.
How many Kilometers did Grandma travel?

Prefixes

In addition to mks units, standard prefixes can be used, e.g., cm, mm, μm, nm

TABLE 1.4

Some Prefixes for Powers of 10 Used with "Metric" (SI and cgs) Units

Power	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^{-1}	deci-	d
10^{1}	deka-	da
10^{3}	kilo-	k
10^{6}	mega-	M
10^{9}	giga-	G
10^{12}	tera-	T
10^{15}	peta-	P
10^{18}	exa-	E

Example 1.4a

$$40\,\mathrm{m} + 11\,\mathrm{cm} = ?$$

The above expression yields:

a) 40.11 m
b) 4011 cm
c) A or B
d) Impossible to evaluate (dimensionally invalid)

Example 1.4b

$$1.5\,\mathrm{m}\times 3.0\,\mathrm{kg} = ?$$

The above expression yields:

a) 4.5 m kg
b) 4.5 g km
c) A or B
d) Impossible to evaluate (dimensionally invalid)

Example 1.4b

$$1.5\,\mathrm{m} - 3.0\,\mathrm{kg\,m/s} = ?$$

The above expression yields:

a) -1.5 m
b) -1.5 kg m^2
c) -1.5 kg
d) Impossible to evaluate (dimensionally invalid)

Example 1

EXAMPLE 1.1 **How Many Atoms in the Cube?**

A solid cube of aluminum (density 2.7 g/cm^3) has a volume of 0.20 cm^3. How many aluminum atoms are contained in the cube?

Solution Since density equals mass per unit volume, the mass m of the cube is

$$m = \rho V = (2.7 \text{ g/cm}^3)(0.20 \text{ cm}^3) = 0.54 \text{ g}$$

To find the number of atoms N in this mass of aluminum, we can set up a proportion using the fact that one mole of aluminum (27 g) contains 6.02×10^{23} atoms:

$$\frac{N_A}{27 \text{ g}} = \frac{N}{0.54 \text{ g}}$$

$$\frac{6.02 \times 10^{23} \text{ atoms}}{27 \text{ g}} = \frac{N}{0.54 \text{ g}}$$

$$N = \frac{(0.54 \text{ g})(6.02 \times 10^{23} \text{ atoms})}{27 \text{ g}} = \boxed{1.2 \times 10^{22} \text{ atoms}}$$

Example 2

EXAMPLE 1.2 **Analysis of an Equation**

Show that the expression $v = at$ is dimensionally correct, where v represents speed, a acceleration, and t a time interval.

Solution For the speed term, we have from Table 1.6

$$[v] = \frac{\mathrm{L}}{\mathrm{T}}$$

The same table gives us L/T^2 for the dimensions of acceleration, and so the dimensions of *at* are

$$[at] = \left(\frac{\mathrm{L}}{\mathrm{T}^{\cancel{2}}}\right)(\cancel{\mathrm{T}}) = \frac{\mathrm{L}}{\mathrm{T}}$$

Therefore, the expression is dimensionally correct. (If the expression were given as $v = at^2$, it would be dimensionally *incorrect*. Try it and see!)

Example 3

EXAMPLE 1.3 **Analysis of a Power Law**

Suppose we are told that the acceleration a of a particle moving with uniform speed v in a circle of radius r is proportional to some power of r, say r^n, and some power of v, say v^m. How can we determine the values of n and m?

Solution Let us take a to be

$$a = kr^n v^m$$

where k is a dimensionless constant of proportionality. Knowing the dimensions of a, r, and v, we see that the dimensional equation must be

$$\mathrm{L}/\mathrm{T}^2 = \mathrm{L}^n(\mathrm{L}/\mathrm{T})^m = \mathrm{L}^{n+m}/\mathrm{T}^m$$

This dimensional equation is balanced under the conditions

$$n + m = 1 \qquad \text{and} \qquad m = 2$$

Therefore $n = -1$, and we can write the acceleration expression as

$$a = kr^{-1}v^2 = k\frac{v^2}{r}$$

When we discuss uniform circular motion later, we shall see that $k = 1$ if a consistent set of units is used. The constant k would not equal 1 if, for example, v were in km/h and you wanted a in $\mathrm{m/s^2}$.

Unit consistency and Conversions

- ❖ When units are not consistent, you may need to convert to appropriate ones
- ❖ Units can be treated like algebraic quantities that can cancel each other out

One can measure the same quantity in different units. For instance distance can be measured in miles, kilometres, meters etc. Velocity can be measured in km/hour, m/s etc.

Conversion of Units: Chain-link method

Example 1: Express 3 min in seconds?

1min = 60 s ➡ $\boxed{1 = \frac{60\text{s}}{1\text{ min}} = \frac{1\text{ min}}{60\text{s}}}$ Conversion Factor?

$$\boxed{3\text{min} = 3\text{min x } 1 = 3\text{min x} \frac{60\text{ s}}{1\text{ min}} = 180\text{ s}}$$

Example 2: How many centimeters are there in 5 meter?

$\boxed{1\text{ m} = 100\text{ cm}}$ ➡ $\boxed{1 = \frac{100\text{ cm}}{1\text{ m}}}$

$$\boxed{5m = 5\text{m x } 1 = 5\text{m x} \frac{100\text{ cm}}{1\text{ m}} = 500\text{ cm}}$$

Example 4

EXAMPLE 1.4 **The Density of a Cube**

The mass of a solid cube is 856 g, and each edge has a length of 5.35 cm. Determine the density ρ of the cube in basic SI units.

Solution Because 1 g = 10^{-3} kg and 1 cm = 10^{-2} m, the mass m and volume V in basic SI units are

$$m = 856 \cancel{\text{g}} \times 10^{-3} \text{ kg}/\cancel{\text{g}} = 0.856 \text{ kg}$$

$$V = L^3 = (5.35 \cancel{\text{cm}} \times 10^{-2} \text{ m}/\cancel{\text{cm}})^3$$
$$= (5.35)^3 \times 10^{-6} \text{ m}^3 = 1.53 \times 10^{-4} \text{ m}^3$$

Therefore,

$$\rho = \frac{m}{V} = \frac{0.856 \text{ kg}}{1.53 \times 10^{-4} \text{ m}^3} = \boxed{5.59 \times 10^3 \text{ kg/m}^3}$$