Physics Lecture Notes - 1

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What is physics?

Physics is a science that helps us understand how things around us work. It studies the basic rules that control matter, energy, space, and time. Physicists use math and experiments to learn more about the world.

Importance and applications of physics

Physics is important because it helps us understand the world and create new inventions. Many things we use every day come from physics. Some examples are:

- Electricity: It gives power to our homes, devices, and factories.
- Electronics: Computers, phones, and communication systems all use physics.
- Medical tools: Physics helps us make machines like MRI scanners and cancer treatments.
- Transportation: Cars, planes, and spaceships use ideas from physics.
- Renewable energy: Solar panels and wind turbines come from studying physics.

Physics also teaches us how to think and solve problems. This is useful in many jobs, not just science.

Basic concepts: force, energy, and motion

Force

A force is a push or pull on an object. It can make the object move, change shape, or change size. Forces have a size and a direction. There are different kinds of forces, like gravity, magnetism, and nuclear forces. Isaac Newton made rules about how forces work, called Newton's laws of motion.

Example: When you push a box, you apply a force to it. The force makes the box move.

Energy

Energy is what lets us do work or make things warmer or cooler. There are many types of energy, like moving energy (kinetic), stored energy (potential), heat, and light. Energy can change from one type to another, but it never disappears completely. This rule is called the law of conservation of energy.

Example: When you lift a book, you give it potential energy. If you let go, the book falls and turns the potential energy into kinetic energy.

Motion

Motion is when an object changes its place over time. Physics studies things like distance, speed, and how fast speed changes. Distance is how far an object moves, and speed is how fast it moves. How fast the speed changes is called acceleration.

Example: When you ride a bike, you and the bike are in motion. If you pedal harder, you will increase your speed and acceleration.

Mathematical equations, problems, and solutions

Force

One of Newton's laws is called the second law of motion. It says that the force on an object is equal to the mass of the object times its acceleration:

$$F = ma$$

Problem: A 10 kg box is pushed with a force of 30 N. What is the acceleration of the box?

Solution: We can use Newton's second law to find the acceleration. First, write down the equation:

$$F = ma$$

Next, plug in the numbers:

$$30\,\mathrm{N} = 10\,\mathrm{kg} \times a$$

Now, solve for the acceleration, a:

$$a = \frac{30\,\mathrm{N}}{10\,\mathrm{kg}} = 3\,\mathrm{m/s}^2$$

So, the acceleration of the box is 3 m/s².

Energy

Kinetic energy (moving energy) is given by the following equation:

$$KE = \frac{1}{2}mv^2$$

Problem: A 5 kg ball is rolling with a speed of 2 m/s. What is its kinetic energy?

Solution: We can use the kinetic energy equation to find the answer. First, write down the equation:

$$KE = \frac{1}{2}mv^2$$

Next, plug in the numbers:

$$KE = \frac{1}{2}(5\,\mathrm{kg})(2\,\mathrm{m/s})^2$$

Now, solve for the kinetic energy, KE:

$$KE = \frac{1}{2}(5\,\mathrm{kg})(4\,\mathrm{m}^2/\mathrm{s}^2) = 10\,\mathrm{J}$$

So, the kinetic energy of the ball is 10 J (joules).

Motion

The equation for calculating the final speed of an object after a certain time, given its initial speed and acceleration, is:

$$v_f = v_i + at$$

Problem: A car starts from rest and accelerates at 4 m/s² for 5 seconds. What is its final speed?

Solution: We can use the motion equation to find the final speed. First, write down the equation:

$$v_f = v_i + at$$

Since the car starts from rest, the initial speed, v_i, is 0 m/s. Next, plug in the numbers:

$$v_f = 0\,\mathrm{m/s} + (4\,\mathrm{m/s^2})(5\,\mathrm{s})$$

Now, solve for the final speed, v_f:

$$v_f = 0\,\mathrm{m/s} + 20\,\mathrm{m/s} = 20\,\mathrm{m/s}$$

So, the final speed of the car is 20 m/s.

Problem Solving Methods

Scientific method

The scientific method is a way to ask and answer questions about the world. It has several steps:

1. Ask a question.
2. Do research and gather information.
3. Make a hypothesis (a guess about what the answer might be).
4. Test the hypothesis with experiments or observations.
5. Analyze the data and draw conclusions.
6. Share the results with others.

The scientific method helps us find the truth by testing our ideas and learning from the results.

Estimation and approximation

Estimation is a way to find an answer that is close enough, even if it is not exact. Approximation is a similar idea, where we use a simpler number or idea to make the problem easier. Both estimation and approximation help us solve problems more quickly and easily.

Example: You want to know how much money you will have after 5 years if you save $1.90 every day. Instead of using $1.90, you can approximate it as $2. Then, you can estimate that you will save about $2 per day x 30 days per month x 12 months per year x 5 years = $3600.

Estimation and approximation can help us make quick decisions and solve problems in our daily lives. Here are some examples:

- Cooking: You can estimate how much salt or sugar to add to a recipe based on your taste preferences.
- Shopping: You can approximate the total cost of the items in your cart to make sure you have enough money before checking out.
- Time management: You can estimate how long it will take you to complete a task and plan your day accordingly.

Problem: You are making a sandwich and want to put about 50 grams of cheese on it. You don't have a scale, but you know a 200-gram block of cheese is about 4 centimeters thick. Estimate the thickness of the cheese slice you need to cut.

Solution: We can use proportions to solve this problem. First, find the ratio of the desired cheese mass to the total mass:

$$\frac{50\,\mathrm{g}}{200\,\mathrm{g}} = \frac{1}{4}$$

Now, multiply the total thickness of the cheese block by this ratio to find the thickness of the slice:

$$\frac{1}{4} \times 4\,\mathrm{cm} = 1\,\mathrm{cm}$$

So, you should cut a 1 cm thick slice of cheese to get approximately 50 grams.

Problem: You have a 2-liter bottle of soda and want to pour it into cups for your friends. Each cup can hold about 250 milliliters. Estimate how many cups you can fill.

Solution: First, convert the volume of the soda to milliliters:

$$2\,\mathrm{L} \times \frac{1000\,\mathrm{mL}}{1\,\mathrm{L}} = 2000\,\mathrm{mL}$$

Now, divide the total volume of soda by the volume of each cup:

$$\frac{2000\,\mathrm{mL}}{250\,\mathrm{mL}} = 8$$

So, you can fill approximately 8 cups with the 2-liter bottle of soda.

Order-of-Magnitude Estimation Problems

Problem 1: Estimate the number of piano keys in a typical grand piano.

Hint: Think about how many octaves a piano might have, and how many keys there are in an octave.

Problem 2: Estimate the number of bricks in a small house.

Hint: Consider the dimensions of a brick and the dimensions of the house.

Problem 3: Estimate the number of heartbeats in a human lifetime.

Hint: Consider the average human lifespan and the typical number of heartbeats per minute.

Problem 4: Estimate the total number of words in a 200-page book.

Hint: Consider the average number of words per page.

Problem 5: Estimate the number of grains of sand in a small sandbox.

Hint: Consider the dimensions of the sandbox and the approximate size of a grain of sand.

Units and measurements

Units are a way to measure things like length, mass, time, and temperature. It is important to use the right units and make sure they match when solving problems.

Some common units are:

- Length: meter (m), kilometer (km), centimeter (cm), millimeter (mm)
- Mass: kilogram (kg), gram (g), milligram (mg)
- Time: second (s), minute (min), hour (h), day
- Temperature: Celsius (°C), Fahrenheit (°F), Kelvin (K)

*Example: If you want to find the distance a car travels in 3 hours at 60 km/h, you must make sure the time is in hours, not minutes or seconds.

SI units

The International System of Units (SI) is a standard system of units used by scientists and engineers worldwide. There are seven base SI units:

- Length: meter (m)
- Mass: kilogram (kg)
- Time: second (s)
- Electric current: ampere (A)
- Temperature: kelvin (K)
- Amount of substance: mole (mol)
- Luminous intensity: candela (cd)

Example: A room's length is measured as 4 meters, its width as 3 meters, and its height as 2 meters. All measurements use the SI unit for length, meters (m).

Problem: A car travels 150 meters in 10 seconds. What is its average speed in meters per second (m/s)?

Solution: To find the average speed, we can use the formula:

$$v_{avg} = \frac{d}{t}$$

Where v_{avg} is the average speed, d is the distance traveled, and t is the time taken.

Plug in the numbers:

$$v_{avg} = \frac{150\,\mathrm{m}}{10\,\mathrm{s}} = 15\,\mathrm{m/s}$$

So, the average speed of the car is 15 m/s.

Problem: A container holds 500 grams of water. Convert the mass of the water to kilograms.

Solution: To convert grams to kilograms, we can use the following conversion factor:

$$1\,\mathrm{kg} = 1000\,\mathrm{g}$$

Divide the mass in grams by 1000 to convert it to kilograms:

$$\frac{500\,\mathrm{g}}{1000\,\frac{\mathrm{g}}{\mathrm{kg}}} = 0.5\,\mathrm{kg}$$

So, the mass of the water is 0.5 kg.

Problem: A light bulb has a luminous intensity of 800 candela (cd). If the bulb is switched on for 2 hours, how much luminous energy is emitted in that time?

Solution: This problem is a bit tricky because luminous intensity and luminous energy are different quantities. However, we can estimate the luminous energy using the following formula:

$$E = P \times t$$

Where E is the energy, P is the power, and t is the time.

First, we need to find the power of the light bulb. Let's assume the power is 60 watts. Now, we can convert the time to seconds:

$$2\,\mathrm{h} \times \frac{3600\,\mathrm{s}}{1\,\mathrm{h}} = 7200\,\mathrm{s}$$

Next, plug in the numbers:

$$E = (60\,\mathrm{W})(7200\,\mathrm{s}) = 432000\,\mathrm{J}$$

So, the light bulb emits approximately 432,000 J (joules) of luminous energy in 2 hours.

SI Units and Unit Conversion Problems

Problem 1: Convert a distance of 75 kilometers to meters.

Problem 2: A car is traveling at a speed of 90 km/h. What is its speed in meters per second?

Problem 3: You have a 500 mL bottle of water. Convert its volume to liters.

Problem 4: A room has a length of 6 meters, a width of 4 meters, and a height of 3 meters. Calculate the volume of the room in cubic meters.

Problem 5: The temperature outside is 30°C. Convert this temperature to Kelvin.

Problem 6: A person weighs 150 pounds. Convert their weight to kilograms, given that 1 pound is approximately 0.453592 kg.

Problem 7: A race takes 3 hours, 15 minutes, and 25 seconds to complete. Convert the race time to seconds.

Problem 8: A car travels a distance of 450 km with an average speed of 120 km/h. Calculate the time it takes to complete the journey, in hours.

Error analysis

In physics, we often make measurements that are not exact. There might be small mistakes or differences between the real value and the measured value. Error analysis is a way to find out how much the measurements might be wrong and how much it affects the final answer.

Types of Errors and Calculating Uncertainty

There are two main types of errors in measurements:

- Systematic error: A consistent error that occurs every time the measurement is made. This can be caused by a faulty instrument, incorrect calibration, or a flawed experimental method.
- Random error: An error that occurs randomly and unpredictably. This can be caused by variations in the environment, human error, or the limitations of the measuring instrument.

To quantify the uncertainty in measurements, we can use the absolute uncertainty and the relative uncertainty:

- Absolute uncertainty: The amount of possible error in the measurement, expressed in the same units as the measurement itself.
- Relative uncertainty: The ratio of the absolute uncertainty to the measured value, often expressed as a percentage.

Problem 1: You measure the length of a table with a ruler and find it to be 150 cm. The ruler has a smallest division of 1 cm, which represents the limit of its precision. Calculate the absolute and relative uncertainties in the measurement.

Solution: The absolute uncertainty is half the smallest division of the ruler, which is 0.5 cm.

The relative uncertainty is the absolute uncertainty divided by the measured value:

$$\frac{0.5\,\text{cm}}{150\,\text{cm}} \approx 0.0033$$

Expressed as a percentage, the relative uncertainty is:

$$0.0033 \times 100\% \approx 0.33\%$$

Problem 2: You measure the mass of a rock with a digital scale and find it to be 425 g. The scale has an uncertainty of ± 3 g. Calculate the absolute and relative uncertainties in the measurement.

Solution: The absolute uncertainty is given as ± 3 g.

The relative uncertainty is the absolute uncertainty divided by the measured value:

$$\frac{3\,\mathrm{g}}{425\,\mathrm{g}} \approx 0.0071$$

Expressed as a percentage, the relative uncertainty is:

$$0.0071 \times 100\% \approx 0.71\%$$

Problem 3: You measure the time it takes for a ball to fall from a certain height and find it to be 1.25 s with an uncertainty of ± 0.05 s. Calculate the absolute and relative uncertainties in the measurement.

Solution: The absolute uncertainty is given as ± 0.05 s.
The relative uncertainty is the absolute uncertainty divided by the measured value:

$$\frac{0.05\,\mathrm{s}}{1.25\,\mathrm{s}} = 0.04$$

Expressed as a percentage, the relative uncertainty is:

$$0.04 \times 100\% = 4\%$$

Dimensional Analysis

Dimensions and Units

In physics, quantities such as length, mass, and time are represented by dimensions. Each dimension has a corresponding unit to measure it. For example, the dimension of length can be measured in meters (m), while the dimension of time can be measured in seconds (s). The International System of Units (SI) provides a standardized set of units for each dimension.

Conversion between Units

Conversion between units is often necessary when working with physical quantities. To convert a quantity from one unit to another, you can use conversion factors. For example, to convert a length from meters to centimeters, you can use the conversion factor 100 cm = 1 m.

$$L_{\mathrm{cm}} = L_{\mathrm{m}} \times \frac{100\,\mathrm{cm}}{1\,\mathrm{m}} \tag{1}$$

Dimensional Homogeneity

An equation in physics is dimensionally homogeneous if the dimensions of each term on both sides of the equation are the same. Dimensional homogeneity is a necessary condition for the validity of a physical equation. It ensures that the equation is consistent in terms of the dimensions of the quantities involved.

Dimensionless Quantities

Dimensionless quantities are quantities that have no dimensions. They are often represented as ratios of quantities with the same dimensions, resulting in the dimensions canceling out. Examples of dimensionless quantities include the coefficients of friction, Reynolds number in fluid dynamics, and the fine-structure constant in quantum mechanics.

Dimensionless quantities are useful in dimensional analysis, as they allow for the comparison of quantities without the need for unit conversion.

More on Dimensional Analysis

Dimensional analysis is a powerful tool in physics that allows us to check the consistency of equations and to derive relationships between physical quantities. The technique involves analyzing the dimensions (or units) of each term in an equation to ensure that both sides of the equation have the same dimensions.

Dimensional Homogeneity

An equation is said to be dimensionally homogeneous if the dimensions of each term on both sides of the equation are the same. This is based on the principle that quantities with different dimensions cannot be added or equated.

Example: The equation for the kinetic energy of an object is given by:

$$E_k = \frac{1}{2}mv^2$$

Where E_k is the kinetic energy, m is the mass of the object, and v is its velocity. The dimensions of the terms are:

- E_k: [M L^2 T^{-2}]
- m: [M]

- v^2: [L^2 T^{-2}]

Multiplying the dimensions of m and v^2 gives us [M L^2 T^{-2}], which matches the dimensions of E_k. Thus, the equation is dimensionally homogeneous.

Dimensionless Quantities

Some quantities, such as angles and ratios, do not have dimensions. These are called dimensionless quantities. For example, the sine and cosine functions of an angle output dimensionless values.

Buckingham Pi Theorem

The Buckingham Pi Theorem is a powerful method in dimensional analysis that allows us to find dimensionless parameters for a given physical problem. This theorem states that if a problem has n physical variables and k fundamental dimensions, then there are $n - k$ dimensionless parameters (or Pi terms) that can be formed from these variables.

Example: The period T of a simple pendulum depends on its length L and the acceleration due to gravity g. We have 3 variables (T, L, and g) and 2 fundamental dimensions (length [L] and time [T]). According to the Buckingham Pi Theorem, there is one dimensionless parameter that can be formed:

$$\Pi = \frac{T\sqrt{g}}{L}$$

This dimensionless parameter is constant for all simple pendulums, regardless of their length or the local gravitational acceleration.

More Dimensional Analysis Examples

Example 1: The gravitational force between two masses m_1 and m_2 separated by a distance r is given by:

$$F = G\frac{m_1 m_2}{r^2}$$

Where F is the gravitational force and G is the gravitational constant. The dimensions of the terms are:

- F: [M L T^{-2}]

- $m_1 m_2$: [M^2]
- r^2: [L^2]
- G: [$\mathrm{M}^{-1}\ \mathrm{L}^3\ \mathrm{T}^{-2}$]

Multiplying the dimensions of G, $m_1 m_2$, and r^2 gives us [$\mathrm{M\ L\ T}^{-2}$], which matches the dimensions of F. Thus, the equation is dimensionally homogeneous.

Example 2: The power P dissipated in an electrical circuit is given by:

$$P = IV$$

Where I is the current and V is the voltage. The dimensions of the terms are:

- P: [$\mathrm{M\ L}^2\ \mathrm{T}^{-3}$]
- I: [I] (current dimension)
- V: [$\mathrm{M\ L}^2\ \mathrm{T}^{-3}\ \mathrm{I}^{-1}$]

Multiplying the dimensions of I and V gives us [$\mathrm{M\ L}^2\ \mathrm{T}^{-3}$], which matches the dimensions of P. Thus, the equation is dimensionally homogeneous.

Example 3: The ideal gas law relates the pressure P, volume V, and temperature T of a gas to the number of moles n and the gas constant R:

$$PV = nRT$$

The dimensions of the terms are:

- P: [$\mathrm{M\ L}^{-1}\ \mathrm{T}^{-2}$]
- V: [L^3]
- n: [N] (amount of substance dimension)
- R: [$\mathrm{M\ L}^2\ \mathrm{T}^{-2}\ \mathrm{N}^{-1}$]
- T: [K] (temperature dimension)

Multiplying the dimensions of n, R, and T gives us [$\mathrm{M\ L}^{-1}\ \mathrm{T}^{-2}\ \mathrm{L}^3$], which matches the dimensions of PV. Thus, the equation is dimensionally homogeneous.

Dimensional Analysis Problem Set

Problem 1: You are designing a water fountain and want to find a relationship between the height h the water reaches, the flow rate Q of the water pump, and the nozzle diameter d. Find the dimensionless parameter for this problem using dimensional analysis.

Problem 2: A car's fuel efficiency depends on its speed v, mass m, air density ρ, and drag coefficient C_d. Find the dimensionless parameter for this problem using dimensional analysis.

Problem 3: The time t it takes for a cup of coffee to cool down depends on its initial temperature T_i, the room temperature T_r, and the heat transfer coefficient h. Find the dimensionless parameter for this problem using dimensional analysis.

Problem 4: The oscillation frequency f of a spring-mass system depends on the mass of the object m, the spring constant k, and the damping coefficient c. Find the dimensionless parameter for this problem using dimensional analysis.

Problem 5: The flow rate Q of a fluid through a pipe depends on the pipe's length L, diameter D, the fluid's viscosity μ, and the pressure difference ΔP between the two ends of the pipe. Find the dimensionless parameter for this problem using dimensional analysis.

Solutions

Solution 1: For the water fountain problem, we have 3 variables (h, Q, and d) and 2 fundamental dimensions (length [L] and time [T]). According to the Buckingham Pi Theorem, there is one dimensionless parameter that can be formed:

$$\Pi = \frac{hQ^2}{d^5}$$

This dimensionless parameter is constant for water fountains with similar designs, regardless of their height, flow rate, or nozzle diameter.

Solution 2: For the car's fuel efficiency problem, we have 4 variables (v, m, ρ, and C_d) and 3 fundamental dimensions (mass [M], length [L], and time

[T]). According to the Buckingham Pi Theorem, there is one dimensionless parameter that can be formed:

$$\Pi = \frac{v^2 m C_d}{\rho}$$

This dimensionless parameter is constant for cars with similar shapes and masses, regardless of their speed or air density.

Solution 3: For the coffee cooling problem, we have 4 variables (t, T_i, T_r, and h) and 3 fundamental dimensions (time [T], temperature [K], and length [L]). According to the Buckingham Pi Theorem, there is one dimensionless parameter that can be formed:

$$\Pi = \frac{t(T_i - T_r)}{h}$$

This dimensionless parameter is constant for coffee cups with similar shapes and initial temperatures, regardless of the time it takes to cool down or the room temperature.

Solution 4: For the spring-mass system problem, we have 4 variables (f, m, k, and c) and 3 fundamental dimensions (mass [M], length [L], and time [T]). According to the Buckingham Pi Theorem, there is one dimensionless parameter that can be formed:

$$\Pi = \frac{f^2 m k}{c}$$

This dimensionless parameter is constant for spring-mass systems with similar damping coefficients, regardless of their oscillation frequency, mass, or spring constant.

Solution 5: For the fluid flow problem, we have 5 variables (Q, L, D, μ, and ΔP) and 3 fundamental dimensions (mass [M], length [L], and time [T]). According to the Buckingham Pi Theorem, there are two dimensionless parameters that can be formed:

$$\Pi_1 = \frac{QD^2}{\mu L}$$

$$\Pi_2 = \frac{\Delta P D^4}{\mu^2 L}$$

These dimensionless parameters are constant for fluid flows with similar pipe lengths and diameters, regardless of the flow rate, fluid viscosity, or pressure difference.

More Problems on Dimensional Analysis:

Problem 5: The speed v of sound in a medium depends on the medium's bulk modulus B and density ρ. The equation for the speed of sound is given by:

$$v = \sqrt{\frac{B}{\rho}}$$

The dimensions of the terms are:

- v: [L T^{-1}]
- B: [M L^{-1} T^{-2}]
- ρ: [M L^{-3}]

Dividing the dimensions of B by ρ gives us [L T^{-1}], which matches the dimensions of v. Thus, the equation is dimensionally homogeneous.

Problem 6: The angular momentum L of an object depends on its mass m, velocity v, and the perpendicular distance r from the axis of rotation. The equation for angular momentum is given by:

$$L = mvr$$

The dimensions of the terms are:

- L: [M L^2 T^{-1}]
- m: [M]
- v: [L T^{-1}]
- r: [L]

Multiplying the dimensions of m, v, and r gives us [M L^2 T^{-1}], which matches the dimensions of L. Thus, the equation is dimensionally homogeneous.

Problem 7: The pressure P of a fluid depends on the fluid's density ρ, gravitational acceleration g, and depth h. The equation for pressure is given by:

$$P = \rho g h$$

The dimensions of the terms are:

- P: $[\mathrm{M\ L^{-1}\ T^{-2}}]$
- ρ: $[\mathrm{M\ L^{-3}}]$
- g: $[\mathrm{L\ T^{-2}}]$
- h: $[\mathrm{L}]$

Multiplying the dimensions of ρ, g, and h gives us $[\mathrm{M\ L^{-1}\ T^{-2}}]$, which matches the dimensions of P. Thus, the equation is dimensionally homogeneous.

Problem 8: The capacitance C of a parallel plate capacitor depends on the permittivity of free space ϵ_0, the area A of the plates, and the distance d between them. The equation for capacitance is given by:

$$C = \frac{\epsilon_0 A}{d}$$

The dimensions of the terms are:

- C: $[\mathrm{M^{-1}\ L^{-2}\ T^{4}\ I^{2}}]$
- ϵ_0: $[\mathrm{M^{-1}\ L^{-3}\ T^{4}\ I^{2}}]$
- A: $[\mathrm{L^{2}}]$
- d: $[\mathrm{L}]$

Dividing the dimensions of $\epsilon_0 A$ by d gives us $[\mathrm{M^{-1}\ L^{-2}\ T^{4}\ I^{2}}]$, which matches the dimensions of C. Thus, the equation is dimensionally homogeneous.

Problem Set - 1

1. The Plank constant h has a value of approximately 6.626×10^{-34} Js. Convert this to eV·s. Note: 1 eV (electronvolt) is approximately 1.602×10^{-19} J.

2. An experiment measures a length L as 15.2 ± 0.1 m, and a time T as 4.7 ± 0.1 s. If the speed V is defined as $V = L/T$, what is the value and uncertainty of the speed?

3. The gravitational constant G has a value of 6.67430×10^{-11} m^{3}kg^{-1}s^{-2} with a relative standard uncertainty of 4.7×10^{-5}. What is the absolute uncertainty in G?

4. A temperature is measured in degrees Fahrenheit and found to be 212 ± 5°F. Convert this measurement to degrees Celsius, including the uncertainty. (The formula to convert Fahrenheit to Celsius is $C = (5/9)(F - 32)$.)

5. A physical quantity Q is defined as $Q = A^a B^b C^c$, where A, B and C are base physical quantities and a, b, and c are their respective powers. Given that the dimensions of A are $[L^1 M^0 T^0]$, B are $[L^1 M^1 T^{-2}]$ and C are $[L^0 M^0 T^1]$, determine the values of a, b and c such that the dimensions of Q are $[L^2 M^1 T^{-2}]$.

6. A famous equation in physics is $E = mc^2$, where E is energy, m is mass, and c is the speed of light. If we wanted to create a new system of units where E has units of mass (i.e., the unit of energy is the same as the unit of mass), what would the unit of speed be in this system? Express your answer in terms of the original units of mass (M), length (L), and time (T).

7. A car's fuel efficiency is measured in miles per gallon (mpg), but we might prefer to measure it in meters per liter for a science experiment. Given that 1 mile is approximately 1600 meters and 1 gallon is approximately 3.8 liters, convert an efficiency of 25 mpg to meters per liter.

8. Given that force F is mass m times acceleration a, and the units of acceleration are meters per second squared (m/s^2), what are the units of force in the SI system? If you were to create a new system of units where the unit of force is defined as the base unit (i.e., it has no units), what would the unit of mass be in this new system?

9. The speed of light c is a fundamental constant of nature, and its value is approximately 3×10^8 m/s. However, we often see this value approximated as $c \approx 1$ in a system of units called "natural units." In this system, what is the unit of length in terms of the original units of length (L), mass (M), and time (T)?