

Physics Basics and Key Forces

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Customized study notes on Physical World and Measurement, especially Physics Basics and Key Forces. These notes are based on NCERT Physics Class XI.

A physics calculation begins with a system, a model and clearly named quantities. Drawing the forces on 1 object is often the best first step in mechanics.

What Is Physics? Understanding the Physics Basics

Physics basics start with a single impulse: curiosity about the natural world. Ever since humans arrived on Earth, they've been driven to ask "why does this happen?" when they watch lightning strike or a ball curve through the air. That curiosity is the foundation of all science, and physics sits right at its core.

Science is a systematic attempt to understand natural phenomena in a detailed and profound manner. **Physics**, specifically, is the branch of natural science that deals with the basic laws of nature and how they manifest across every natural phenomenon you can observe.

Physicists work to explain diverse natural phenomena using a handful of **scientific laws and concepts**. **Newton's law of gravitation**, for instance, explains both why an apple falls and why the Moon orbits Earth. James Clerk **Maxwell's equations** unify electricity, magnetism, and light into one elegant framework. Galileo Galilei laid the groundwork for modern mechanics by studying motion and inertia centuries before Newton formalized his three laws.

Reductionism is a method at the very heart of physics. The idea is straightforward: you study the interactions and properties of smaller, simpler parts to understand larger, more complicated systems. If you can figure out how atoms behave, you can predict how materials behave. That's reductionism in action, and it's why physicists like Richard Feynman described it as "the art of finding the simplest explanation."

Physics basics revolve around understanding the universe through observation, measurement, and mathematical modeling. Every physics concept you'll encounter, from Newton's laws to Einstein's relativity, follows this same pattern: observe, measure, model, predict, verify.

Scope and Excitement of Physics

The scope of physics basics extends from the smallest subatomic particles to the largest structures in the cosmos. Physics has two main domains of interest: **macroscopic** and **microscopic**. **Classical physics** is mostly concerned with macroscopic phenomena, the things you can see and measure directly. It includes subjects like mechanics, thermodynamics, optics, and electrodynamics.

However, classical physics falls short when you move to the microscopic domain. At the scale of atoms and subatomic particles, you need **quantum theory**, which is now accepted as the correct framework for explaining microscopic phenomena. Max Planck introduced this idea in 1900 when he solved the black-body radiation problem, and Niels Bohr applied it to atomic structure just 13 years later.

There's also an emerging domain called **mesoscopic physics**, which sits between the macroscopic and the microscopic. It deals with systems of a few tens or hundreds of atoms, a fascinating middle ground where quantum effects start to show up in measurable ways.

Physics basics span over 85 orders of magnitude in mass alone. The electron weighs about 10^{-30} kg, while the observable universe clocks in at roughly 10^{55} kg. No other science covers a range this vast, which is exactly why physics is considered the most fundamental natural science.

The scope of physics is staggeringly wide, and that's what makes it exciting. Consider just the **scale of length**: physics deals with everything from protons and electrons at 10^{-14} m or less, all the way up to galaxies spanning 10^{26} m. The entire observable universe stretches to the order of 10^{40} m or more. For a deeper dive into how physicists handle these numbers, check the study notes on **units and measurements**.

The **scale of mass** is equally impressive. You go from 10^{-30} kg (the mass of an electron) to 10^{55} kg (the mass of the observable universe). That's 85 orders of magnitude in a single discipline.

The **time scale** ranges from around 10^{-22} seconds to 10^{18} seconds. You can estimate these by dividing the corresponding length scales by the speed of light. Physics truly covers everything from the unimaginably tiny to the incomprehensibly vast. Accurate measurement at every scale depends on understanding **significant figures** and precision.

Physics, Technology, and Society

A strong connection has always existed between physics, technology, and society. Every major technological leap in human history traces back to a physics breakthrough. Michael Faraday's discovery of electromagnetic induction in 1831 eventually led to electric power generation. Heinrich Hertz's experimental confirmation of Maxwell's electromagnetic waves in 1887 paved the way for radio, television, and wireless communication.

Technology has also given rise to new physics. The field of thermodynamics, for example, emerged

because scientists like Sadi Carnot and Rudolf Clausius were trying to improve the working of heat engines. The practical need drove the theoretical discovery.

Think about it: how did humanity progress from the simple wheel to the space shuttle? Many of the facilities you rely on every day, from the internet to mobile phones to microwave ovens, exist because of physics. You're reading this on a device that wouldn't exist without quantum mechanics and semiconductor physics.

Physics holds great importance in **medicine** as well. Wilhelm Rontgen's accidental discovery of X-rays in 1895 revolutionized medical diagnostics. Today, technologies like MRI (based on nuclear magnetic resonance discovered by Isidor Rabi), Doppler ultrasound, electrocardiography (ECG), and endoscopy all stem from physics principles. If you've ever had a medical scan, you've directly benefited from physics.

The development of biotechnology and material technology has depended heavily on **microscopic instruments** such as the electron **microscope** (EM) and the atomic force microscope (AFM). These tools let you see and manipulate matter at the atomic level.

Physics also drives the development of **alternative energy resources** like solar energy, geothermal energy, and hydroelectricity. Albert Einstein's 1905 explanation of the photoelectric effect (which earned him the Nobel Prize in 1921) is the theoretical foundation behind every solar cell you see today.

Despite all this progress, many questions remain unanswered. Are matter and energy two different aspects of the same entity? Can the different forces in nature be unified into a single framework? These open questions are what keep physics alive and thrilling.

Reduction and **unification** are two important thrusts in physics. Reduction means explaining complex phenomena through simpler underlying laws. Unification means showing that seemingly different forces are actually different aspects of a single force. Both have driven some of the greatest breakthroughs in the history of science.

Fundamental Forces in Nature

Main article: Fundamental forces

Understanding the fundamental forces is one of the most important physics basics you'll encounter. You're already familiar with the concept of force from everyday life. Push a door, throw a ball, feel the wind on your face, those are all forces. In the macroscopic world, you encounter **gravitational force, friction, viscous force, elastic force**, and many more. In the microscopic domain, there's **electric force, magnetic force, nuclear force**, and others.

Here's the remarkable discovery of 20th-century physics: all these seemingly different forces arise from just a small number of **fundamental forces** in nature. This insight came from decades of work by physicists including Sheldon Glashow, Abdus Salam, and Steven Weinberg, who shared

the 1979 Nobel Prize for unifying two of these forces.

Consider the elastic spring force as an example. When you compress or stretch a spring, the restoring force comes from the net attraction or repulsion between neighboring atoms. That atomic-level interaction is itself the result of electric forces between charged constituents. So the spring force is really just the electromagnetic force in disguise.

This means the laws governing derived forces are ultimately dependent on the laws of fundamental forces. As of now, you need to know about **four fundamental forces** in nature, each discussed in detail below.

Gravitational Force

Gravitational force is a **universal force of mutual attraction** between any two objects by virtue of their **masses**. Isaac Newton formalized this in his 1687 work *Principia Mathematica*, showing that the force is proportional to the product of the masses and inversely proportional to the square of the distance between them. Every object in the universe experiences this force due to every other object.

Gravity is a **long-range force** and **does not need any intervening medium**. It works across the vacuum of space just as well as it works here on Earth's surface. It is, however, the **weakest force in nature** compared to the other three fundamental forces.

Despite being the weakest, gravity dominates at large scales. It governs the motion of satellites around the Earth, planets around the Sun, and the formation and evolution of galaxies, stars, and galactic clusters. Johannes Kepler's three laws of planetary motion, formulated between 1609 and 1619, were later explained by Newton's gravitational theory. When you're dealing with massive objects, gravity is the force that matters most.

When solving gravitational problems, remember that the gravitational constant $G = 6.674 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$. This tiny value is exactly why gravity is so weak at small scales but dominant at astronomical scales where masses are enormous.

Electromagnetic Force

Electromagnetic force is the force acting between **charged particles**. When charged particles are at rest, the force between them is called the **static electric force**, described by **Coulomb's law** (formulated by Charles-Augustin de Coulomb in 1785). It's attractive for unlike charges and repulsive for like charges.

When charges move, they produce **magnetic effects**. Hans Christian Oersted demonstrated this connection in 1820 when he showed that an electric current deflects a compass needle. A magnetic field, in turn, exerts a force on other moving charges. Since the electric and magnetic effects are deeply intertwined, you can't really separate them. The combined effect is what we call the **electromagnetic force**.

Like gravity, the electromagnetic force is a **long-range force** and **does not need any intervening medium**. But here's where it gets interesting: the electromagnetic force is vastly stronger than gravity. The electric force between two stationary protons is 10^{36} times the gravitational force between them at any given distance. That's why it dominates all phenomena at atomic and molecular scales. For more on how forces relate to motion, see [kinematic equations](#).

Strong Nuclear Force

You already know that an atom's nucleus contains protons (positively charged) and neutrons (no charge). Now think about this: protons are all positively charged and packed into an incredibly tiny space. The electric repulsion between them should blow the nucleus apart instantly.

Gravity is far too weak to hold the nucleus together, as we've already established. So what keeps it stable? The answer is the **strong nuclear force**, a fundamentally different force that **binds protons and neutrons** within the nucleus. Hideki Yukawa predicted this force in 1935, proposing that it's mediated by particles he called mesons.

The strong nuclear force is about 100 times stronger than the electromagnetic force, making it the **strongest of all fundamental forces**. However, it's a short-range force, effective only over distances of about 10^{-15} m, roughly the size of a nucleus.

An important property: this force is **independent of charge**. It acts equally between two protons, two neutrons, or a proton and a neutron. Electrons, being outside the nucleus, don't experience this force at all.

At an even deeper level, protons and neutrons are themselves made of more elementary particles called **quarks**. Murray Gell-Mann proposed the quark model in 1964. The strong force between quarks, mediated by particles called gluons, is the true fundamental interaction at work here. This is described by the theory of quantum chromodynamics (QCD).

Weak Nuclear Force

The weak nuclear force shows up in specific nuclear processes, most notably the **beta-decay of a radioactive nucleus**. In beta decay, the nucleus emits an electron and an uncharged particle called a **neutrino** (first proposed by Wolfgang Pauli in 1930 and experimentally detected by Clyde Cowan and Frederick Reines in 1956).

When a neutrino interacts with other particles, it does so through the weak nuclear force. You won't encounter this force in everyday life because it operates at extremely small scales.

The weak nuclear force is stronger than gravity but much weaker than both the electromagnetic and strong nuclear forces. Its range is extremely small, on the order of 10^{-16} m. Despite its limited reach, it plays a crucial role in processes like nuclear fusion in stars, which is ultimately why the Sun shines. Enrico Fermi first developed a theory of the weak force in 1933, and it was later refined into the electroweak theory.

Memorize this ranking from strongest to weakest: Strong Nuclear > Electromagnetic > Weak Nuclear > Gravitational. The strong force is roughly 100x stronger than electromagnetic, 10^{13} x stronger than weak nuclear, and 10^{38} x stronger than gravity. This comparison shows up in nearly every physics basics exam. For a detailed breakdown, read the notes on the four fundamental forces of nature.

Towards Unification of Forces

Unification is one of the deepest quests in physics basics and advanced physics alike. The question is simple but profound: do all four fundamental forces arise from a single, underlying force? For centuries, physicists have been chasing this idea.

Some major milestones have already been achieved. Newton unified terrestrial and celestial mechanics in 1687, showing that the same gravity that pulls an apple down also keeps planets in orbit. Maxwell unified electricity and magnetism into electromagnetism in the 1860s with his four famous equations. In the 1970s, Sheldon Glashow, Abdus Salam, and Steven Weinberg showed that the electromagnetic and weak nuclear forces were unified into the **electroweak force**. The search continues for a Grand Unified Theory (GUT) that would also include the strong force, and ultimately a Theory of Everything that incorporates gravity. For more on how Einstein's work contributes to this quest, see the notes on [special relativity](#).

Eminent scientists like Newton, Faraday, Oersted, Maxwell, and Einstein have all contributed to this venture. Each step toward unification has revealed a deeper symmetry in nature, suggesting that the universe is more elegant than it appears on the surface.

Nature of Physical Laws

Conservation laws are among the most powerful physics basics you'll use throughout your studies. When you study a physical phenomenon governed by various forces, you'll notice something interesting: many physical quantities change with time, but certain special quantities remain constant throughout. These unchanging quantities are called **conserved quantities**, and they're some of the most powerful ideas in all of physics.

Conservation laws aren't just mathematical conveniences. They reflect deep symmetries of nature (as proven by Emmy Noether in her landmark 1918 theorem) and provide you with powerful shortcuts for solving problems. Here are the fundamental conservation laws you need to know.

Law of Conservation of Energy

Energy can neither be created nor destroyed. It can only be converted from one form to another. The total amount of energy in an isolated system, and indeed in the universe as a whole, remains

constant. James Prescott Joule's experiments in the 1840s established the mechanical equivalent of heat, confirming that thermal energy and mechanical energy are interchangeable. When you see a ball rolling to a stop, its kinetic energy hasn't vanished. It's been converted to heat through friction.

Law of Conservation of Charge

The algebraic sum of all electric charges always remains constant during any process taking place in an electrically isolated system. Benjamin Franklin first proposed the principle of charge conservation in the 1740s. You can move charges around, separate them, or combine them, but you can never create or destroy net charge.

Law of Conservation of Linear Momentum

As long as there is no resultant external force on a system, its total linear momentum remains constant. This is why a rifle kicks back when fired: the bullet's forward momentum is exactly balanced by the rifle's backward momentum. The total stays the same.

Law of Conservation of Angular Momentum

As long as there is no resultant external torque acting on a system, its total angular momentum remains constant. This is why an ice skater spins faster when she pulls her arms in: reducing her moment of inertia increases her rotational speed to keep angular momentum conserved.

These conservation laws have a deep connection with the symmetries of nature. Energy conservation is linked to time symmetry, momentum conservation to spatial symmetry, and angular momentum conservation to rotational symmetry. Emmy Noether's theorem formally proved these connections, and you'll explore them in greater detail in more advanced physics courses. For foundational measurement concepts that underpin all these laws, review [units and measurements](#).

The [OpenStax physics textbooks](#) develop the corresponding physical models with further worked problems.

From a Story to a Model

A 2 kg trolley is pushed horizontally with 10 N while friction opposes its motion with 2 N. The horizontal net force is 8 N, so its acceleration is 4 m/s^2 . Weight and the support force balance vertically if there is no vertical acceleration.

The trolley alone is the chosen system. The push, friction, weight and support force are external to it. If you instead choose the trolley and its pusher as a larger system, some interactions become

internal. The same event can be analyzed with different boundaries, but the forces included must match the selected system.

The points to check in this example are:

- A free-body diagram shows forces acting on the selected object.
- A model states approximations such as constant mass or negligible air resistance.
- Units and limiting cases supply useful checks on a calculated result.

Check Your Understanding

Try the questions before reading the answers.

Question 1. What is the trolley acceleration if friction rises to 10 N?

Answer. Zero, provided the push stays 10 N.

Question 2. Does zero acceleration require zero velocity?

Answer. No. Constant nonzero velocity also has zero acceleration.

Practice Questions

Work each question before reading its solution. The set runs from direct recall and substitution to the applied questions that exams actually use to separate grades. The downloadable PDF includes these questions and their solutions.

Question 1. Distinguish distance from displacement: a jogger runs 300 m east, then 300 m west. State both.

Solution. Distance, the path length, is 600 m. Displacement, the net change of position, is 0: she ends where she began. Distance is a scalar and only grows; displacement is a vector and can cancel. Speed and velocity inherit exactly this split.

Question 2. A car accelerates uniformly from rest to 24 m/s in 8 s. Find the acceleration and the distance covered.

Solution. $a = \frac{\Delta v}{t} = 3 \text{ m/s}^2$. Distance from the average speed: $\bar{v} = 12 \text{ m/s}$, so $d = 12 \times 8 = 96 \text{ m}$ (or $d = \frac{1}{2}at^2 = 96 \text{ m}$). Uniform acceleration means the average is the midpoint of start and end speeds.

Question 3. State Newton's 3 laws in one sentence each.

Solution. First: without a net force, velocity does not change. Second: net force produces acceleration by $F = ma$. Third: forces come in equal and opposite pairs acting on different bodies. Everything in mechanics is these 3 sentences plus geometry.

Question 4. A 60 kg person stands in an elevator accelerating upward at 2 m/s^2 . What does the scale read?

Solution. The scale supplies the normal force: $N - mg = ma$, so $N = 60(9.8 + 2) = 708 \text{ N}$, reading about 72 kg. Accelerating down would subtract. The scale measures the support force, not gravity, which is why free fall reads zero: weightlessness without leaving Earth's gravity.

Question 5. Why do a feather and a hammer fall together on the Moon but not on Earth?

Solution. Gravitational acceleration is mass-independent: $F = mg$ and $a = F/m = g$ for everything. On Earth air resistance, which depends on shape and speed rather than mass alone, holds the feather back. Remove the air, as Apollo 15 demonstrated on camera, and they land together.

Question 6. A 2 kg block is pushed with 10 N against 4 N of friction. Find the acceleration.

Solution. Net force = $10 - 4 = 6 \text{ N}$, so $a = 6/2 = 3 \text{ m/s}^2$. The recipe never changes: draw the forces, sum them with signs, divide by mass. Forgetting that only the NET force accelerates is the most common early error.

Question 7. Contrast energy and power: climbing a flight of stairs slowly versus sprinting up. What differs and what does not?

Solution. The work against gravity, mgh , is identical either way: energy does not care about time. Power, energy per time, differs enormously: the sprint delivers the same joules in a fifth of the time at 5 times the power. Electric bills charge for energy (kWh); motor ratings advertise power (W).

Question 8. A 0.5 kg ball is dropped from 20 m. Ignoring air resistance, find its speed at the ground, 2 ways.

Solution. Energy route: $v = \sqrt{2gh} = \sqrt{392} \approx 19.8 \text{ m/s}$. Kinematics route: $v^2 = 2 \times 9.8 \times 20$, the same equation in disguise. Two formalisms, one answer: when both apply, energy is usually fewer steps.

Question 9. Momentum: a 1,000 kg car at 20 m/s hits a stationary 1,000 kg car and they lock together. Find their common speed and check kinetic energy.

Solution. Momentum conserves: $20,000 = 2000 \times v$, so $v = 10 \text{ m/s}$. Kinetic energy before: 200 kJ; after: $\frac{1}{2}(2000)(100) = 100 \text{ kJ}$. Half the energy became deformation, sound, and heat. Momentum survives every collision; kinetic energy survives only elastic ones.

Question 10. What makes a physics answer wrong even when the arithmetic is right? Name 3 checks a finished answer must pass.

Solution. Units: the dimensions must match the quantity asked. Magnitude: a 4,000 m/s bicycle or a 2-gram car fails the plausibility sniff. Direction and sign: vectors need both, and a negative time usually flags the wrong root. Professionals run these 3 checks reflexively; the habit costs 10 seconds and catches most disasters.

Recommended Reading

Mastering physics basics requires the right resources alongside these notes. If you're looking for structured textbooks that cover everything from Newtonian mechanics to modern physics, check out our curated list of the [best physics textbooks for college](#). Pairing these notes with a solid textbook like Halliday, Resnick, and Walker's *Fundamentals of Physics* or H.C. Verma's *Concepts of Physics* will give you both conceptual depth and problem-solving practice.

What are physics basics and why should you study them?

Physics basics cover the foundational concepts of how the natural world works, including forces, energy, motion, and the properties of matter. Studying these basics gives you the tools to understand everything from why objects fall to how electricity powers your devices. Newton's laws, conservation principles, and the four fundamental forces form the core of physics basics that every science student needs.

Why is gravity considered the weakest fundamental force?

When you compare the gravitational force between two protons to the electromagnetic force between them, the electromagnetic force is about 10^{36} times stronger. The strong nuclear force is even more powerful. Gravity only appears dominant in everyday life because it's always attractive (never repulsive) and because large objects like the Earth have enormous mass. At the atomic scale, gravity is so weak that physicists can safely ignore it in most calculations.

What is the strong nuclear force and why is it important?

The strong nuclear force is the strongest of all four fundamental forces. It binds protons and neutrons together inside the atomic nucleus, overcoming the intense electromagnetic repulsion between positively charged protons. Hideki Yukawa predicted this force in 1935. Without it, no atomic nucleus heavier than hydrogen could exist, which means no complex matter, no chemistry, and no life. It operates only over extremely short distances of about 10^{-15} m.

What does unification of forces mean in physics?

Unification means showing that forces which appear different are actually different manifestations of a single underlying force. Maxwell unified electricity and magnetism into electromagnetism in the 1860s. In the 1970s, Glashow, Salam, and Weinberg unified the electromagnetic and weak nuclear forces into the electroweak force. Physicists are still working toward a Grand Unified Theory that would include the strong nuclear force, and ultimately a Theory of Everything that incorporates gravity.

What are conserved quantities and why do they matter?

Conserved quantities are physical quantities that remain constant over time during a process, provided certain conditions are met. Energy, electric charge, linear momentum, and angular momentum are the key conserved quantities. Emmy Noether proved in 1918 that each conservation law corresponds to a symmetry of nature. They give you powerful shortcuts for solving problems, letting you relate initial and final states directly instead of tracking every force at every instant.

What is reductionism in physics?

Reductionism is the approach of understanding complex systems by studying their simpler constituent parts. In physics, this means you break down a complicated phenomenon into its fundamental components and study their interactions. For example, understanding how individual atoms interact helps you explain the properties of materials, gases, and liquids. Richard Feynman championed this approach, and it has led to the discovery of quarks, leptons, and the fundamental forces that explain a vast range of natural phenomena.

What is mesoscopic physics?

Mesoscopic physics is an emerging domain that sits between classical macroscopic physics and quantum microscopic physics. It deals with systems containing a few tens to hundreds of atoms, where quantum effects begin showing up in measurable ways. This field helps bridge the gap between our everyday experience and the strange behavior of subatomic particles, making it a growing area of physics basics research.

How does physics connect to everyday technology?

Virtually every modern technology traces back to a physics discovery. Faraday's electromagnetic induction (1831) led to electric power generation. Maxwell's electromagnetic wave theory enabled radio, TV, and wireless communication. Einstein's photoelectric effect explanation (1905) is the foundation of solar cells. Semiconductor physics, rooted in quantum mechanics, made computers and smartphones possible. Even medical technologies like X-rays, MRI, and ultrasound are direct applications of physics basics.