Physics begins with a strange truth: nothing around us is actually still.

The floor feels solid, but its atoms are vibrating. Earth is spinning while traveling around the Sun. The Sun is moving through the Milky Way, and the Milky Way is moving through space. Even when we sit completely still, we are traveling at enormous speed. We do not feel it because everything near us is moving along with us.

Imagine sitting inside a smoothly moving airplane with the windows covered. If the plane moves in a straight line at a steady speed, we could toss a ball upward and catch it normally. The ball would not fly toward the back of the plane because it already shares the plane's forward motion. We, the ball, and the air inside are all moving together.

This means there is no single, universal answer to "Are we moving?" We must always ask, "Moving compared with what?" We are still compared with the seat, moving compared with the road, and moving extremely fast compared with the Sun.

Now imagine a basketball sitting on the floor. The ball will remain there until something pushes or pulls it. Once we roll it, it continues moving until friction, air resistance, a wall, or another object changes its motion. Objects do not naturally seek rest. They continue doing what they are already doing unless a force interferes.

That stubbornness is called inertia. Every object has it.

Our body shows inertia whenever a vehicle suddenly stops. The vehicle stops first, but our body tries to continue moving forward. A seat belt supplies the force that stops us along with the vehicle. Without it, the windshield, dashboard, or ground would have to provide that stopping force.

The same thing happens when a vehicle suddenly accelerates. We feel pushed backward into the seat, but no mysterious force has grabbed us from behind. Our body is trying to remain in its previous state while the seat moves forward and catches us.

Mass tells us how strongly an object resists having its motion changed. A bowling ball and a tennis ball can sit perfectly still, but the bowling ball is harder to start moving. Once both are moving at the same speed, the bowling ball is also harder to stop. It has more mass and therefore more resistance to change.

Weight is different from mass. Mass belongs to the object. Weight comes from gravity pulling on that mass. If we took a bowling ball to the Moon, its mass would remain the same, but it would weigh less because the Moon's gravitational pull is weaker.

A force is simply a push or a pull. The important part is not how many forces exist but what they produce when combined.

A book resting on a table has gravity pulling it downward. The table pushes upward on the book. These forces balance, so the book does not accelerate. The fact that the book is not moving does not mean no forces are acting on it. It means the forces are balanced.

Imagine two people pushing opposite sides of a couch. One pushes right with the same strength that the other pushes left. The couch remains still because the forces cancel. If the person pushing right becomes stronger, the couch accelerates toward the right. The remaining force after everything is combined is called the net force.

Force, mass, and acceleration work together. A stronger net force produces greater acceleration. A larger mass produces less acceleration when the same force is used.

Push an empty shopping cart, and it accelerates easily. Fill the same cart with bottled water and try the same push. The cart still moves, but not as quickly. Our muscles supplied a similar force, but the larger mass resisted the change.

This relationship is written:

$$F = ma$$

It means:

$$\text{force} = \text{mass} \times \text{acceleration}$$

We do not need to fear the letters. They are labels. The equation is saying that changing the movement of something heavy requires more force than changing the movement of something light.

Whenever we push something, it pushes back. Press our hand firmly against a wall. We feel pressure in our hand because the wall is pushing back against us. If the wall did not push back, our hand would pass through it.

When we jump, our legs push the ground downward, and the ground pushes us upward. When we walk, our foot pushes backward against the ground, and the ground pushes our body forward. On perfectly smooth ice, our foot cannot grip well enough to push backward, so the ground cannot push us forward effectively.

A rocket uses the same rule. It throws hot gases downward at tremendous speed, and the gases push the rocket upward. The rocket does not need air beneath it. It can move through space because it pushes exhaust in one direction and receives a push in the opposite direction.

Now pick up a ball and hold it above the ground. The ball is not moving, but it has stored energy because of its position. If released, gravity can pull it downward and turn that stored energy into motion.

The higher we raise the ball, the more gravitational potential energy it stores. The heavier the ball, the more energy it stores at the same height. When the ball falls, its potential energy decreases while its kinetic energy—the energy of motion—increases.

Just before the ball hits the ground, it is moving fastest. After impact, some of its energy becomes sound, heat, movement in the floor, and deformation of the ball. If it bounces, some energy returns to upward motion. It never bounces higher than where it began unless another source adds energy.

Energy does not disappear. It changes form and spreads.

Our body changes chemical energy from food into movement and heat. A flashlight changes chemical energy in its battery into electrical energy, then light and heat. A speaker changes electrical energy into the movement of a cone, which creates sound waves. A vehicle changes stored chemical or electrical energy into motion, heat, and sound.

People sometimes say that a machine “uses up” energy. A better description is that the machine transforms concentrated, useful energy into forms that are harder to reuse. The heat leaving an engine still exists, but it is scattered through the surroundings.

Speed affects motion energy more strongly than most people realize. If a vehicle moves twice as fast, it does not carry only twice the kinetic energy. It carries four times as much.

This is because kinetic energy depends on speed multiplied by itself:

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

The small 2 means speed is squared. A change from twenty to forty miles per hour doubles the speed but multiplies the kinetic energy by four. This is why higher-speed crashes become dramatically more destructive and why stopping distance grows so quickly.

A moving object also has momentum. Momentum combines mass and velocity. A heavy object moving slowly can have considerable momentum, and a light object moving quickly can also have considerable momentum.

Think about catching a baseball. If the ball is moving slowly, we can stop it easily. If it arrives at high speed, stopping it requires more force. Instead of holding our hands completely stiff, we move them backward while catching it. This gives the ball more time to stop, reducing the force on our hands.

Airbags work through the same principle. A person’s momentum must change from moving to stopped. The airbag increases the time over which that change happens and spreads the force across a larger area of the body. A short, violent stop causes more damage than a slightly longer, controlled stop.

Now consider gravity. People often imagine gravity as something that exists only near Earth, but every object with mass attracts every other object with mass. We pull gravitationally on Earth, and Earth pulls on us. Earth’s motion is unnoticeable because it is enormously more massive.

If gravity pulls the Moon toward Earth, why does the Moon not crash into us?

The Moon is falling toward Earth, but it is also moving sideways. As gravity bends its path downward, Earth’s curved surface falls away beneath it. The Moon keeps falling and keeps missing.

That is an orbit.

Imagine throwing a ball horizontally from a mountain. A gentle throw lands nearby. A stronger throw travels farther before gravity brings it down. If we could throw it fast enough and remove the air resistance, the ground would curve away at the same rate the ball fell. The ball would circle Earth.

Astronauts in orbit are not floating because gravity has disappeared. Gravity at the altitude of the International Space Station is still strong. Astronauts appear weightless because they, their spacecraft, and everything inside are falling around Earth together. There is no floor holding them up in the usual way.

A bathroom scale does not directly measure gravity. It measures how strongly the floor pushes upward against us. In orbit, the astronaut and scale fall together, so the scale has no ordinary supporting force to measure.

Friction is another force that deserves a better reputation. Friction resists sliding between surfaces. It can waste energy as heat, but life would be nearly impossible without it.

We need friction to walk, turn a vehicle, hold a cup, write with a pencil, tie shoes, and stop a bicycle. Vehicle brakes use friction to transform motion energy into heat. Tires need friction with the road to accelerate, stop, and turn.

If a vehicle travels around a curve, its direction is changing. Since velocity includes direction, the vehicle is accelerating even if the speedometer does not move. Friction between the tires and road provides the inward force that bends the vehicle’s path.

Our body seems to lean outward during a turn because inertia tries to carry us in a straight line while the vehicle changes direction underneath us. The door or seat then pushes us inward so that we follow the curve.

When a ball is tied to a string and swung in a circle, the ball constantly tries to continue straight. The string pulls it toward the center, continually changing its direction. If the string breaks, the ball does not fly directly outward from the circle. It moves along the straight direction it was traveling at the instant of release.

Physics becomes even more interesting when we stop thinking only about objects and begin thinking about waves.

Drop a pebble into a pond. Ripples travel outward, but the water does not travel across the entire pond with them. Individual pieces of water mainly move up and down while the disturbance carries energy outward.

A stadium wave works similarly. Each person stands and sits in roughly the same location, but the pattern travels around the stadium. The people are the medium; the wave is the moving pattern.

Sound works by creating patterns of pressure in matter. A speaker cone moves forward and compresses nearby air molecules. It then moves backward, leaving the molecules more spread out. These alternating compressions travel through the air until they reach our eardrums.

Sound needs matter. It can travel through gases, liquids, and solids, but it cannot travel through a perfect vacuum. An explosion in outer space may release light and moving debris, but there is no surrounding air to carry its sound to a distant observer.

Pitch depends mainly on frequency, which means how quickly the vibration repeats. A guitar string vibrating rapidly creates a higher pitch. A string vibrating more slowly creates a lower pitch. Tightening a string usually raises its pitch because the tighter string vibrates faster.

Loudness is connected with the wave’s amplitude, or the size of its vibration. A strongly vibrating speaker moves more air and creates a more intense sound. High pitch and loud sound are different properties. A sound can be high and quiet or low and loud.

Light also behaves like a wave, but it does not need air, water, or another material to carry it. That is why sunlight can cross empty space to reach Earth.

The light we see is only a small portion of a much larger family. Radio waves, microwaves, infrared, visible colors, ultraviolet, X-rays, and gamma rays are all electromagnetic radiation. Our eyes simply detect one narrow section.

Color depends on which wavelengths of visible light reach our eyes. A red object does not contain “redness” as a substance. Under white light, its surface absorbs many wavelengths and reflects more of the wavelengths we experience as red. If no light reaches it, the object has no visible color for us to see.

A mirror works because its smooth surface reflects light in an organized way. We see ourselves because light travels from a source, reflects from our body, hits the mirror, and reflects into our eyes. The image seems to exist behind the mirror because our brain assumes light traveled in a straight line from that direction.

Heat is also easier to understand when we imagine particles moving. In a hot object, particles generally possess more random kinetic energy than particles in a colder object. Heat is energy moving from a warmer place toward a cooler one because of a temperature difference.

Place a metal spoon in hot soup. The fast-moving particles in the hot end transfer energy through the metal, eventually warming the handle. This is conduction.

Warm air rising is convection. The heated air expands, becomes less dense than nearby cooler air, and rises while cooler air moves downward. This circulation helps spread energy through rooms, oceans, and Earth’s atmosphere.

Sunlight warming our skin is radiation. Energy travels through electromagnetic waves and does not require direct contact. This is how the Sun warms Earth across millions of miles of space.

Cold does not move into an object. Heat moves out of it. When we hold an ice cube, energy transfers from our warmer hand into the colder ice. Our hand feels cold because it is losing thermal energy.

Electricity starts with charge. Electrons have negative charge, while protons have positive charge. Opposite charges attract, and like charges repel.

Rub a balloon against hair. Electrons transfer between the materials. The balloon and hair develop an imbalance of charge, causing the strands of hair to rise and move toward the balloon. Nothing magical entered the balloon. Charged particles changed location.

A battery creates an electrical push called voltage. If we connect the battery through a complete circuit, that push causes charge to move. The movement of charge is electric current.

A circuit must form a complete path. If the path is broken, current cannot continue through the circuit. A light switch does not need to “create” electricity. It opens or closes the path.

Resistance makes it harder for current to flow. A thin wire usually has more resistance than a thick wire made from the same material. Resistance can transform electrical energy into heat, which is useful in a toaster but dangerous in overloaded household wiring.

Magnetism and electricity are parts of the same force. Moving electrical charges create magnetic fields. A changing magnetic field can push charges and create an electric current.

An electric motor uses electricity and magnetism to create motion. A generator uses motion and magnetism to create electricity. They perform opposite transformations using the same relationship.

The strange part arrives when we look inside matter. Everything around us is made of atoms. An atom contains a tiny nucleus made of protons and neutrons, surrounded by electrons. Most of the atom’s volume is not packed with solid material in the everyday sense.

If an atom’s nucleus were enlarged to the size of a small marble placed at the center of a stadium, the electrons would occupy regions far away, and most of the stadium would contain empty space.

Why, then, can we not walk through a wall?

The electrons in our body interact with the electrons in the wall through electromagnetic forces. Quantum rules also prevent the particles from simply stacking into identical states. What feels like solid contact is largely electrical resistance between atoms, not tiny hard balls physically pressing together in the way we imagine.

When we sit in a chair, the atoms in our body never truly merge with the atoms in the chair. Electromagnetic forces push back strongly enough to support us.

At the smallest level, particles do not behave like miniature versions of basketballs. Quantum physics describes them using probabilities. An electron does not always occupy one neat path around an atomic nucleus. It is described by a spread of possible locations until an interaction produces a particular result.

This does not mean human thought can command particles to create any reality we want. Quantum physics follows strict mathematical rules. Its strange behavior has been tested so successfully that it powers lasers, computer chips, medical equipment, solar panels, and modern electronics.

Time itself is not completely fixed. Einstein showed that motion and gravity affect how time passes. A clock moving extremely fast runs slightly slower compared with a clock moving more slowly. A clock closer to a strong gravitational field also runs at a different rate from one farther away.

These effects are tiny during ordinary life, but satellites experience enough difference that navigation systems must correct for them. Without relativity, GPS locations would gradually become inaccurate.

Mass and energy are also connected:

$$E = mc^2$$

This equation says that mass is a concentrated form of energy. The cc represents the speed of light, which is an enormous number. Squaring it produces an even larger number, so a small amount of mass can correspond to an extraordinary amount of energy.

The Sun shines partly because nuclear fusion converts a small amount of mass into energy. Deep inside the Sun, hydrogen nuclei combine under tremendous temperature and pressure. Some mass becomes energy, which eventually travels outward and reaches Earth as light and heat.

The sunlight reaching our skin began with events inside the Sun and took roughly eight minutes to cross space. When we look at the Sun, we are seeing it as it was about eight minutes earlier. When we look at distant stars, we may be seeing light that began traveling before we were born.

Looking across space is also looking backward in time.

Physics is not a pile of unrelated formulas. It is a connected way of seeing. A falling ball introduces gravity, motion, force, acceleration, potential energy, kinetic energy, sound, heat, and deformation. A guitar introduces tension, vibration, frequency, waves, air pressure, hearing, electricity, and magnetism. A vehicle introduces combustion or batteries, friction, momentum, inertia, heat, force, and energy.

The strongest way to learn it is to keep asking the same questions: What is moving? What is changing its motion? Where is the energy stored? Where is the energy going? What forces are acting? What would happen if one condition changed?

Once those questions become natural, the world begins explaining the equations before we ever write them down.