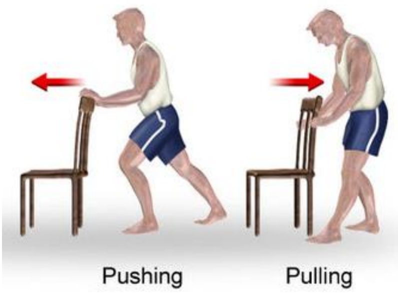
Name: ____ Date: _______

PHYSICS
UNIT 2: FORCES & ACCELERATION

INTRODUCTION TO FORCES

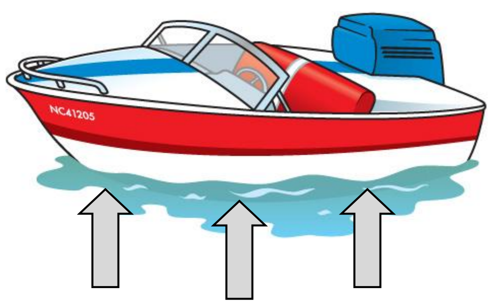
What Are Forces?

Forces are push or pull actions that occur when one object interacts with another object. **Forces cause objects to accelerate**—forces make objects speed up, slow down, or change direction. Remember, **acceleration is the change in velocity**: a change in rate of motion (getting faster or slower with time) or a change in direction. Forces are **vectors** just like velocity and acceleration, and must have both a magnitude (how strong, how big) and a direction. Forces may be positive or negative depending on the direction of influence or action. If the acceleration is positive, the force causing the acceleration is positive. If the acceleration is negative, the force causing the acceleration is negative.



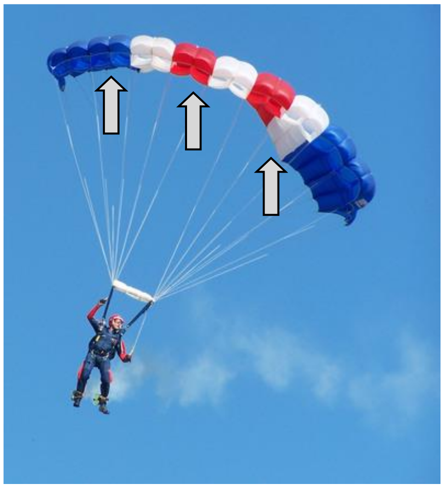
Contact Forces

Some forces are **contact forces**—objects need to touch, or have physical contact with each other for one to exert a force upon the other. Examples of contact forces include friction, air resistance, buoyancy, tension, and impacts.

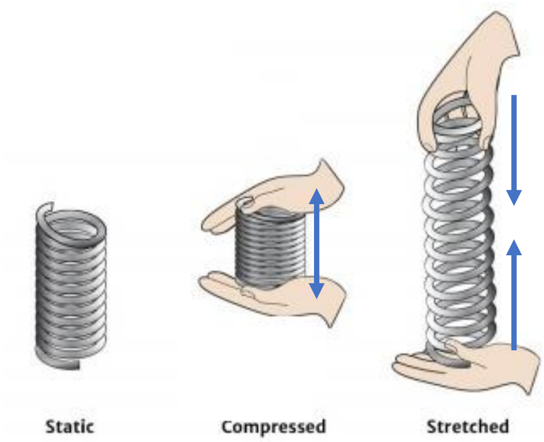


Buoyancy is a contact force and a push force. The water in the lake is touching the bottom and sides of the boat. The force of buoyancy from the water pushes upward onto the boat keeping the boat afloat at the surface.

Tension is a contact force and a pull force. The force of tension is directed through the rope in opposite directions as the rope is pulled.



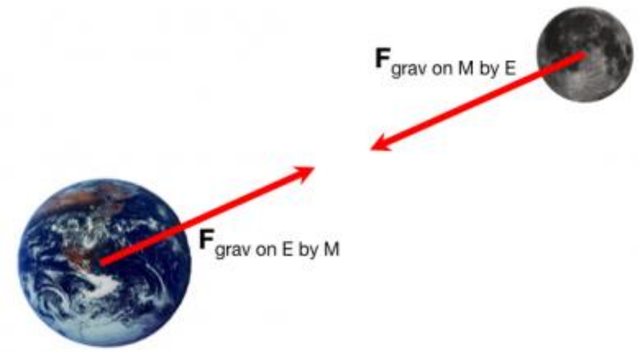
Air resistance is a contact force and a push force. As objects move through air, the object collides with the air molecules. The air molecules in turn push back on the object. Air resistance force acts in the direction opposite of the object's motion. If the object was falling, air resistance pushes up—that's how a parachute works. If the object was moving up, air resistance pushes down, the direction opposite of the object's motion.



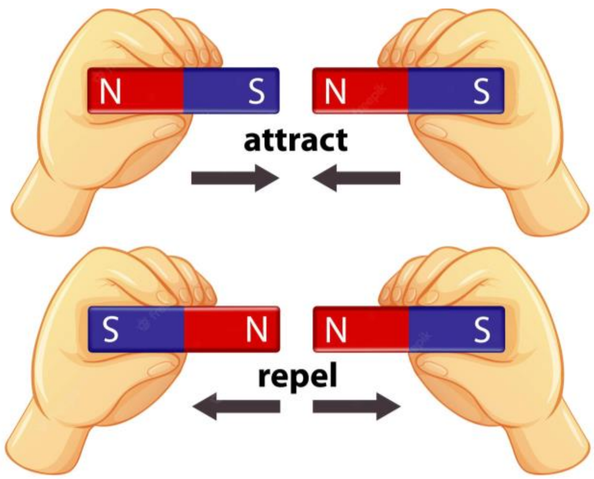
Spring force is the internal restoring force within a spring that acts to restore the spring's shape when it is stretched or compressed. Spring force is a contact force, and depending on the direction of the deformation, a pull or push force.
If a spring is stretched from its static position (at rest), the spring force will pull the ends of the spring inward to make its original shape. If the spring is compressed, the spring force will push the spring outward into to make its original shape.

Action-at-a-Distance Forces

Some forces are **action-at-a-distance forces** or **non-contact forces** or **field forces.** Objects do not need to touch each other for one to exert a force upon the other. The forces pass through space, air, liquids, and solids. Action-at-a-distance forces include gravity force, magnetic force (magnetism), and electrostatic force (electricity).



Gravitational attraction force is an action-at-a-distance force and a pull force. Objects pull on each other with force that is equal in magnitude and opposite in direction. For example., Earth's moon and the Earth are pulling on each other with equal and opposite forces despite not touching each other. The pull force of gravity between Earth and moon keeps Earth's moon in orbit around the Earth.



Magnetic force is an action-at-a-distance force, and depending on the orientation of the magnets, they may be a pull or push force. Opposite poles of two different magnets (N & S) will attract each other. Like poles of two different magnets (N & N, S & S) will repel each other.

Electrostatic force is an action-at-a-distance force, and depending on the combination of charges, the force may be a pull or push force. Objects with opposite charges (+ and -) will pull on each other. Objects with like charges (+ and +, - and -)

Mass and Weight

Mass is defined as the quantity of matter contained within an object. Mass tells us “how much stuff” is inside objects. **Mass is a conserved property of matter**, meaning that mass is constant regardless of location, the forces acting upon the object, or the motion of the object. In other words, **mass never changes**.

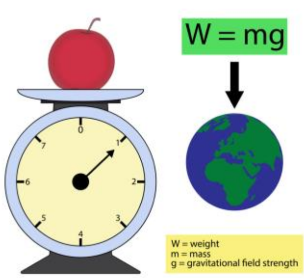
Illustrative Example 1

The student desk in this room has a mass of 50 kg.

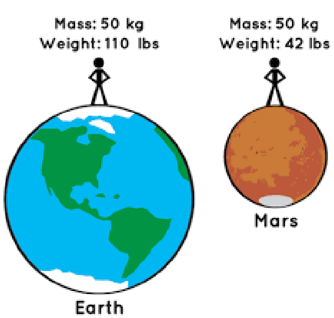
The same student desk on a spaceship flying to Mars with a speed of 10,000 km/hr has a mass of 50 kg.

The same student desk at the bottom of the Atlantic Ocean has a mass of 50 kg.

Regardless of the desk’s location or motion, the desk is still the same desk and will have a mass of 50 kg. Mass never changes.



Weight is the downward force, or heaviness of an object, caused by the gravitational attraction between an object on a planet or moon’s surface and the planet or moon. Weight is dependent on the planet or moon, but independent of the object’s mass on the planet or moon’s surface.



In the example to the left, the person will have different weights on the Earth and on Mars, however, the person’s mass will remain constant because he has the same amount of matter in his body on both planets. Again, mass remains constant regardless of location or force acting upon it.

Inertia

Inertia is an object's resistance to changing its state of motion. **Inertia** is the object's resistance to accelerate. Objects, because of their mass, naturally resist forces that act upon them. Objects want to keep their current states of motions. Objects do not want to accelerate. They want to "keep doing what they are already doing."

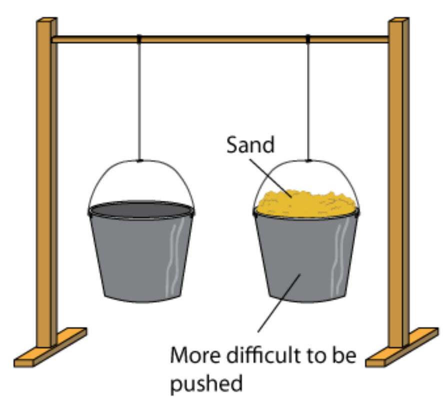
Objects that are motionless resist forces that try to put them into motion.

Objects that are in motion want to stay in motion. They resist forces that try to make them go faster, go slower, or change direction.

Inertia is proportional to the mass of the object. Larger objects resist more against forces that act upon them; larger objects strongly resist acceleration. Smaller objects resist less against force that act upon them; smaller objects weakly resist acceleration. As a result, more massive objects require more force to be accelerated because they have more inertia due to their larger mass and resist forces more strongly. Conversely, less massive objects require lesser force to be accelerated because they have less inertia due to their smaller mass and little resistance to forces.

Illustrative Example 2

The empty bucket has less mass, therefore has less inertia. As a result, the empty bucket can be easily pushed or pulled by a weak force—less mass means less resistance to accelerating by a force. In contrast, the bucket filled with sand has a very large mass. As a result, a stronger force is needed to push or pull the sand-filled bucket—greater mass means more resistance to accelerating by a force.



Illustrative Example 3

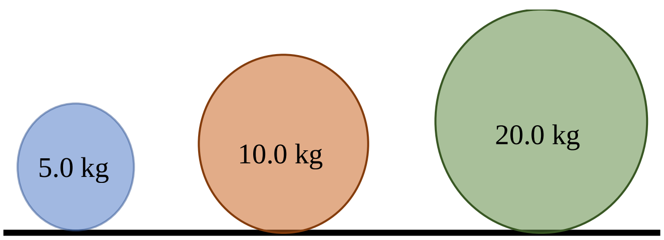
Small mass = small inertia = Less resistance

The tennis ball has a very small mass, thus it weakly resists acceleration. The impact force of the tennis racket against the tennsis ball will easily change its velocity by moving the ball faster and in the opposite direction.

Big mass = Big inertia = More resistance

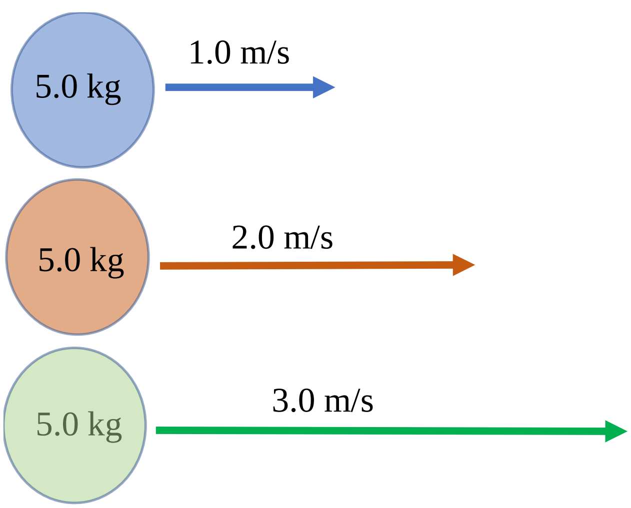
The elephant has a huge mass and very large inertia. It will resist forces and resist moving unless the force acting upon it is very, very large.

Illustrative Example 4



The 5.0 kg ball is less resistance to force, it will accelerate with less force. The 10.0 kg ball is more resistance to force, it will accelerate with stronger force. The 20.0 kg ball has the most resistance to force, it. will accelerate with a very strong force.

Illustrative Example 5



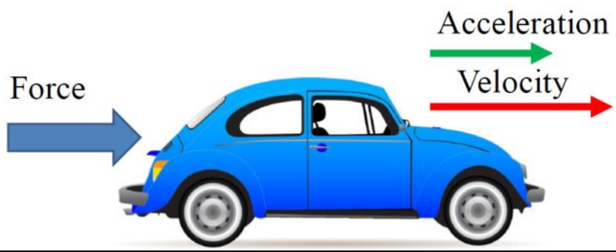
Three 5.0 kg balls are moving at different velocities. Regardless of the differences in their velocities, they have equal inertia. Inertia only depends on mass. Inertia is independent on motion. Equal amounts of force applied to all three balls will cause equal acceleration despite that they are moving at different velocities.

Forces Cause Acceleration

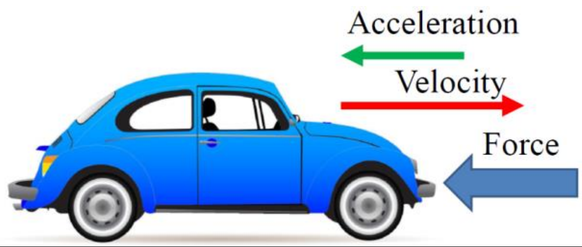
An unbalanced force causes objects to accelerate. Remember, acceleration is the change in velocity. Forces will cause objects to accelerate by getting faster with time, getting slower with time, or changing directions. When forces act upon objects, **the acceleration of the object is always in the direction of the force.** If the force pushes the object to the right, the acceleration is the right. If the force pushes the object to the south, the direction of the acceleration is to the south.

Illustrative Example 6

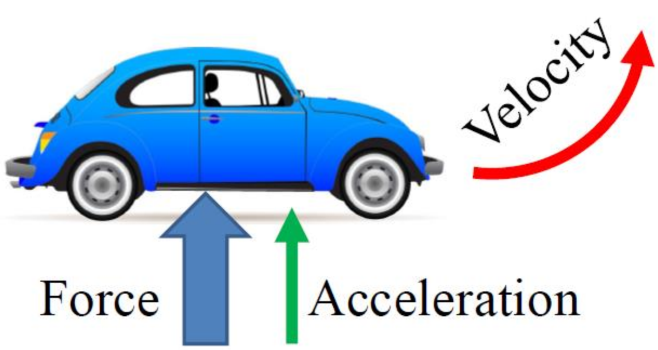
Getting faster: The force acts on the moving car in the same direction that the car is already moving. Acceleration will be in the same direction as the motion of the car. The car will get faster with time.



Getting slower: The force acts on the moving car in the opposite direction to which the car is moving. Acceleration will be in the direction opposite of the moving car. The car will get slower with time.

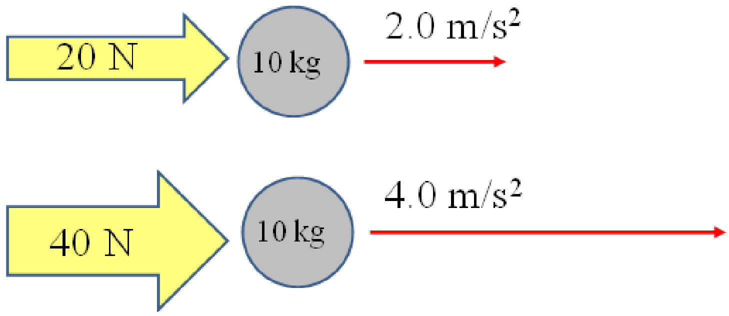


Changing direction: The force acts on the moving car at an angle (not straight on) relative to the car's motion. The car will accelerate by changing direction. The car will turn. The acceleration is in the same direction as the force acting on the car.



Acceleration is proportional to the force acting upon the object. The application of a weak force will create a small acceleration—the change in velocity will be very gradual and slow. The application of a strong force will create a greater acceleration—the change in velocity will be very sudden and fast.

Illustrative Example 7



The 10 kg ball will experience a weaker acceleration when pushed by the 20 N force. The same 10 kg ball will experience a stronger acceleration when pushed by the 40 N force. Stronger force will cause a greater acceleration—the ball will go farther faster.

Calculating Forces

Force is calculated as the product of mass (kg) times acceleration (m/s^2). Forces are reported in units of **Newtons** (N), named after Sir Isaac Newton. In the USA, the unit for force is the pound (lb). Units of Newtons are N = kg·m/s^2. Note that the **mass must always be in kg** and **acceleration must always be in m/s^2**.

Force = Mass x Acceleration

The force equation may be rearranged to solve for acceleration or mass.

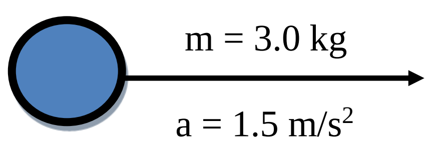
$$F_{net} = m \cdot a \qquad a = \frac{F_{net}}{m} \qquad m = \frac{F_{net}}{a}$$

F = force (N) [Net force acting upon object]
a = acceleration (m/s^2)
m = mass (kg)
N = newtons (unit of force, $N = kg\frac{m}{s^2}$)

Calculation Example 1

A 3.0 kg ball is accelerated at 1.5 m/s^2. Calculate the applied force acting upon the ball.

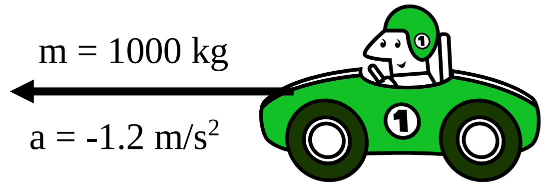
$$F_{net} = m \cdot a = 3.0\ \text{kg} \cdot 1.5\ {}^{m}/_{s^2} = 4.5\ \text{N}$$



Calculation Example 2

A car's engine accelerates the car by -1.2 m/s^2. The mass of the car is 1000 kg. Calculate the force of the engine accelerating the car.

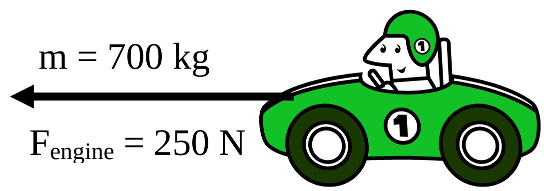
$$F_{net} = m \cdot a = 1000 \text{ kg} \cdot -1.2\, {}^{m}/_{s^2} = -1200 \text{ N}$$



Calculation Example 3

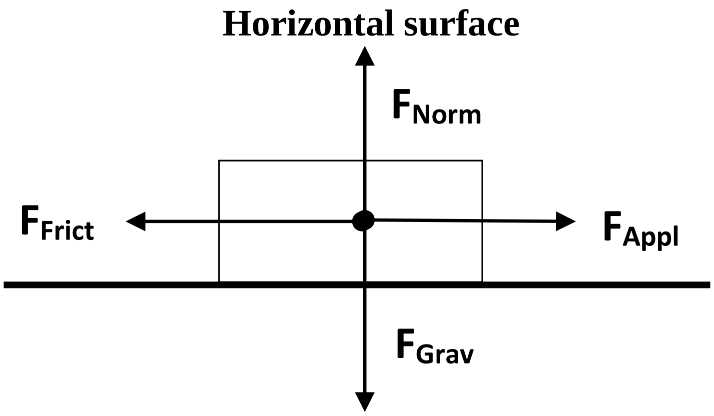
A car's engine uses a force of 250 N to move accelerate the car. Calculate the acceleration.

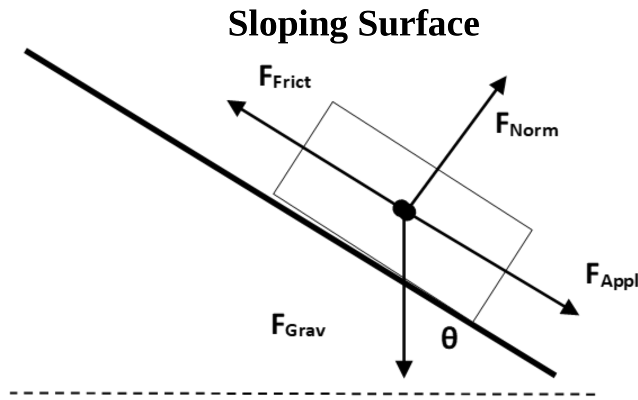
$$a = \frac{F_{net}}{m} = \frac{250N}{700kg} = 0.357\frac{m}{s^2}$$



Basic Free Body Diagrams

Free body diagrams are drawings that show a simplistic representation of a real-life object (represented as a square or circle) with all the external forces that simultaneously act it. The object (the "free body") is normally drawn as a square or rectangle, and will represent any object like a car, human, bird, rocket, etc… It is easier to draw a square or rectangle than to draw a complex object—the square or rectangle is for simplicity. The vector arrows on the free body represent the forces. Force vector arrows originate in the center of the free body and are drawn such that the tip of the vector arrows point in the direction of influence. Any number of forces can be drawn on the free body diagram. If an object is being affected by 10 different forces at the same time, then 10 vector arrows representing those forces will be drawn on the diagram.





Under most circumstances, there are four main forces that act upon most objects on Earth's surface.

Gravity force (F_{Grav}) is the weight of the object pressing down onto the surface. Gravity force is caused by the mutual gravitational attraction between the object and the Earth. Gravity force is always present, and is always in the down direction regardless of surface's slope or tilt.

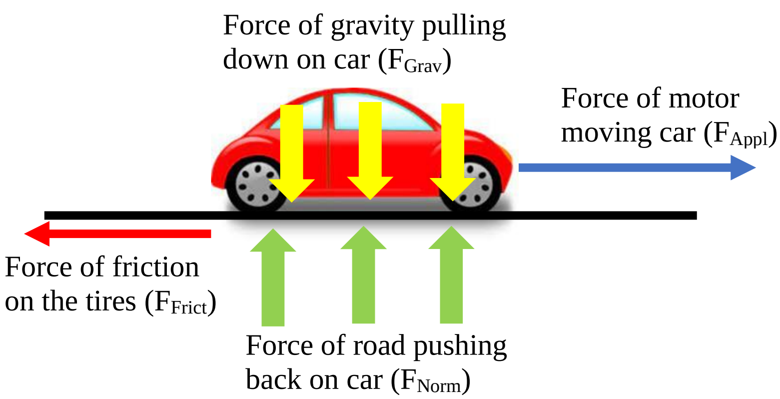
Normal force (F_{Norm}) is is the "push-back" force by the against the object. Normal force is the supporting force. Normal force is always perpendicular to the surface regardless of the surface's slope or tilt.

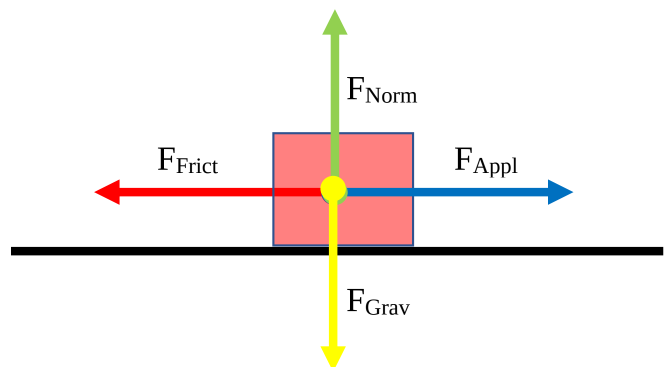
Applied force (F_{Appl}), sometimes called the **action force**, is a push or pull force added to an object with the intent of moving the object or to keep the object moving. The applied force gives the object motion. The applied force is directed parallel to the surface over which the object moves, and in the same direction as intended motion. If the object is not being pushed or pulled, applied force is zero.

Friction force (F_{Frict}) is the resisting or dissipative force that occurs at the contact between two surfaces in contact. Friction force causes objects to grip the surface over which they move at the contact between the object and surface. Friction force always acts parallel to the surface and in the direction opposite that the object moves.

Illustrative Example 8

A car is acted upon by four forces: Force of the motor (F_{Appl}), Friction force between the road and the tires (F_{Frict}), Gravity force pulling the car downward against the road (F_{Grav}), and Normal force of the road pushing back on the car (F_{Norm}). A more detailed picture is shown on the left. The free body diagram representing the car and all forces acting on the car is to the right. The surface is horizontal. Applied force and Friction force are parallel to the surface, with Friction force in the direction opposite the car's motion. Gravity force is in the down direction. Normal force is perpendicular to the surface, which coincidentally is in the up direction for this example.





Illustrative Example 9

A car is acted upon by four forces: Force of the motor (F_{Appl}), Friction force between the road and the tires (F_{Frict}), Gravity force pulling the car downward against the road (F_{Grav}), and Normal force of the road pushing back on the car (F_{Norm}). A more detailed picture is shown on the left. The free body diagram representing the car and all forces acting on the car is to the right. The surface is sloping. Again, the Applied force and Friction force are parallel to the surface, with Friction force in the direction opposite the car's motion. Gravity force is always in the down direction. Normal force is always perpendicular to the surface, which is diagonally up in this case.