Section 4.1 - Gravitational Force Near Earth

Learning Goal: By the end of today, I will be able to identify the part the force of gravity plays in sky diving and with objects on a ramp.

Winged Base Jumping - Yikes! 8:00 min

All of the fun stuff to do in the world is built on the knowledge of physics.

Which object is accelerating?

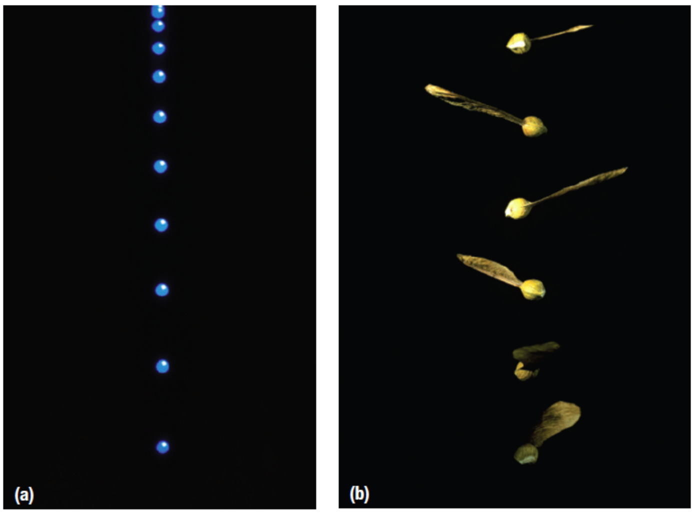


Figure 2 (a) Multi-flash photograph of a ball in free fall starting from rest (b) Multi-flash photograph of a light object with large surface area in free fall. Which object is accelerating? How can you tell?

Force of Air Resistance Factors

When an object has a larger cross-sectional area, it experiences more air resistance. Another factor that affects the force of air resistance is the speed of the object. Faster-moving objects experience more air resistance. Air resistance acts opposite to the direction of motion of the object if there is no wind.

Big Area = Big Resistance

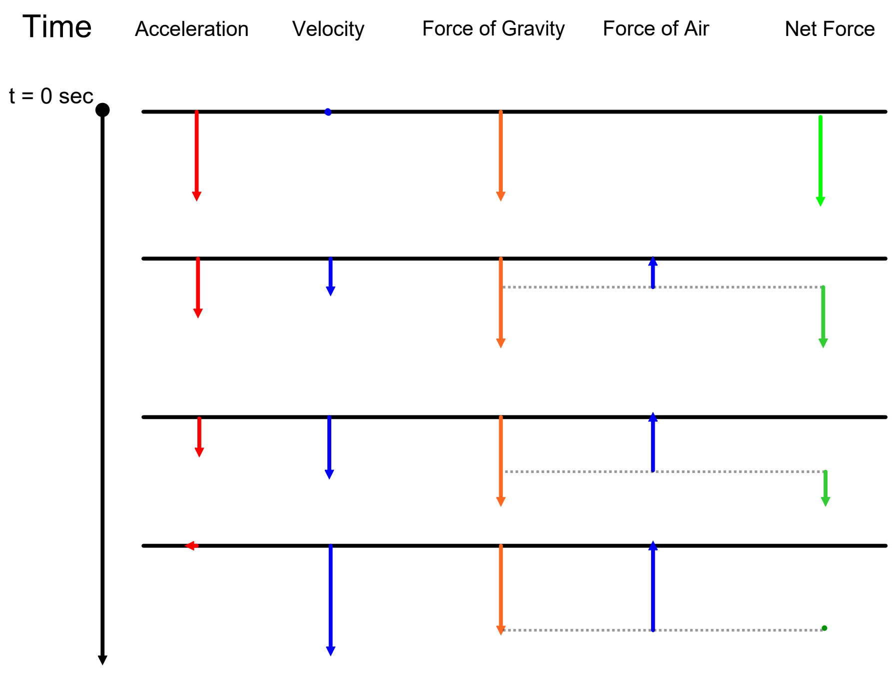
Faster Moving = Bigger Resistance

The Flight of the Skydiver

The skydiver jumps out of the plane and starts falling. The instant the skydiver leaves the plane, her initial velocity in the vertical direction is zero and she experiences very little air resistance.

As the skydiver continues to fall, her speed increases and she is now accelerating. As the speed of the skydiver increases, the magnitude of air resistance acting on her also increases .

During the time that the air resistance is increasing, the net force on the skydiver is decreasing. This means that the acceleration of the skydiver is decreasing. Eventually the magnitude of air resistance becomes great enough that it equals the magnitude of the force of gravity. At this moment, the skydiver is moving at constant speed. The maximum constant speed reached by a falling object is called the terminal speed.



Would the parachute open the instant she jumped out of the plane? Why or why not?

Why does the parachute open?

What happens after the parachute opens? (in physics terms please)

To slow down, the skydiver must increase the force of air resistance acting on her body. To do this, the skydiver must increase her cross-sectional area moving through the air. As soon as the parachute opens, the upward force of air resistance is much greater in magnitude than the downward force of gravity. So the skydiver begins to slow down because the net force is directed upward while she is still falling downward. Since the speed of the skydiver is decreasing, the force of air resistance acting on the skydiver also decreases. Eventually the air resistance decreases to the point where its magnitude again equals the force of gravity. Now the skydiver is moving at a much slower terminal speed than before and she can land safely on the ground.

① { initial jump → $F_g > F_{air}$ → accelerate down
→ moving = down
F_{net} = down

② free fall $F_g = F_{air}$ → $F_{net} = 0$ No accl'n
→ moving down @ constant velocity

③ open chute (initial) $F_g < F_{air}$ → accelerate up
F_{net} = up
→ moving down but at a decreasing vel.

④ open chute free fall $F_g = F_{air}$ → No acceleration
→ moving down at a reduced velocity from ②

The Difference between Mass and Weight

The terms “mass” and “weight” are used interchangeably in everyday language, but these two words have different meanings. Mass is the quantity of matter in an object. The only way to change the mass of an object is to either add or remove matter. The mass of an object does not change due to location or changes in gravitational field strength. The units of mass are kilograms, and mass is measured using a balance.

Weight is a measure of the force of gravity, F_g, acting on an object. Since weight and the force of gravity are the same quantity, the weight of an object depends on location and the magnitude of Earth’s gravitational field strength at that location. Weight is a vector, and its magnitude is measured in newtons with a spring scale or a force sensor. When measuring weight with a force sensor or a spring scale, the object must either be at rest or moving at a constant velocity while being supported by the scale or sensor

Gravitational Field Strength

A FORCE FIELD is a region of space surrounding an object that can exert a force on other objects; the field exerts a force only on objects placed within that region that are able to interact with that force.

The GRAVITATIONAL FIELD STRENGTH is the force, per kilogram of mass, acting on an object within a gravitational field. The gravitational field strength is a vector quantity because it has a direction. The gravitational field strength due to Earth always points toward Earth's centre. Gravitational field strength has units of newtons per kilogram. At Earth's surface, the gravitational field strength is 9.8 N/kg [down].

Figure 4 The gravitational force field surrounding Earth attracts all other objects placed within this field. The magnitude of Earth's gravitational field decreases as an object moves farther away from Earth's surface.

$$\frac{9.8N}{kg} = \frac{9.8\frac{kg\cdot m}{s^2}}{kg} \quad or \quad \frac{9.8m}{s^2}$$

$$\vec{F} = m\cdot\vec{g}$$

$$\vec{g} = \frac{\vec{F}}{m}$$

At the top of Mount Everest at an altitude of 8848 m above sea level, the magnitude of the gravitational field strength is 9.7647 N/kg.

Force of Gravity Around the World

Since Earth is not a perfect sphere, the magnitude of the gravitational field strength at Earth's surface varies according to the geographic location of the object.

Earth bulges out slightly at the equator due to the rotation of the planet. At the poles, an object at sea level is 21 km closer to Earth's centre than if it were at sea level at the equator. This means that the magnitude of the gravitational field strength is slightly greater at the poles than at the equator. The magnitude of the gravitational field strength gradually increases with latitude as you travel from the equator toward either pole.

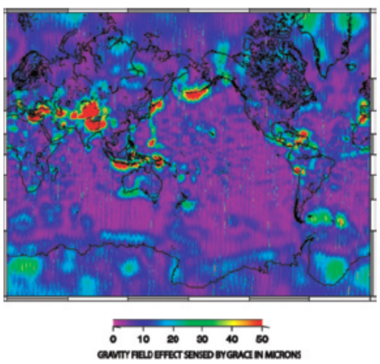


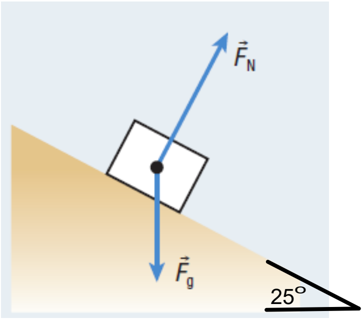
Figure 5 The magnitude of the gravitational field strength varies depending on the location on Earth's surface. On this map, red and yellow areas have a greater gravitational field strength.

A Cart on an Incline - Free Body Diagram

A 5kg cart is on an incline plane at an angle of 25°.

We can ignore friction for this example.

What is the normal force acting on the cart?



What is the acceleration of the cart?

Bathroom Scale Problem

A 60.0 kg person is standing on a bathroom scale calibrated in newtons. A friend pushes down on the person with a force of 72.0 N. What is the reading on the scale?

Practice

1. A 12 kg box sits on top of a 38 kg box. T/I C
   (a) Draw an FBD for each box.
   (b) Calculate the normal force acting on the 12 kg box. [redacted]
   (c) Calculate the normal force acting on the 38 kg box due to the floor. [redacted]
2. A child has a mass of 36 kg and is sitting on a seat on an amusement park ride. The ride makes the seat move up and down. Determine the normal force acting on the child when the child is
   (a) moving up at a constant velocity of 12 m/s [redacted]
   (b) moving down at a constant velocity of 14 m/s [redacted]
   (c) accelerating down at 1.8 m/s^2 T/I [redacted]
3. A 72 kg person jumps up off a bathroom scale. Determine the acceleration of the person when the scale reads 840 N. T/I [redacted]
4. An electrician holds a 3.2 kg chandelier against a ceiling with a force of 53 N [up]. What is the normal force exerted by the ceiling on the chandelier? T/I [redacted]

4.1 Questions

1. Use Newton's second law and the force of gravity to explain why all objects fall with the same acceleration in the absence of air resistance. K/U
2. Explain why a person with an open parachute has a lower terminal speed than a person with a closed parachute. K/U
3. Why do light objects with large cross-sectional areas fall more slowly in air than heavy objects with small cross-sectional areas? K/U
4. In an action movie, a plane releases a heavy box while in flight. The box is attached to a parachute that opens as soon as it leaves the plane. Part of the way down to the ground, the parachute malfunctions and the box breaks free. Describe the forces acting on the box while it is falling and use them to describe the velocity and acceleration of the box. Use FBDs to explain your reasoning. K/U C
5. An astronaut with a mass of 74 kg goes up to the ISS on a mission. During his stay, the gravitational field strength on the station is 8.6 N/kg. T/I
   (a) What is the mass of the astronaut on the station?
   (b) What is the difference between the astronaut's weight on Earth's surface and his weight on the station?
   (c) Why does the weight of the astronaut change but not his mass when moving from the surface of Earth to the station?
   (d) Why does the astronaut appear weightless on the station?
6. Copy and complete **Table 1** by calculating the weight of an object of mass 20.000 kg at different latitudes on Earth. Use the results to answer the following questions. T/I

Table 1

Latitude (°)	Weight of object (N)	$\vec{g}$ (N/kg [down])	Distance from Earth's centre (km)
0 (equator)		9.7805	6378
30		9.7934	6373
60		9.8192	6362
90 (North Pole)		9.8322	6357

   (a) What is the difference in the weight of the object from the equator to the North Pole?
   (b) Why does the weight change at different latitudes?
   (c) Explain why the gravitational field strength increases with latitude.
7. A cargo box on a rocket has a mass of 32.00 kg. The rocket will travel from Earth to the Moon. K/U T/I
   (a) What will happen to the mass of the cargo box during the mission? Explain your reasoning.
   (b) Determine the weight of the box at the surface of Earth.
   (c) The weight of the box on the Moon is 52.06 N. Determine the gravitational field strength on the surface of the Moon.
8. Summarize the differences between mass and weight by copying and completing **Table 2**. K/U

Table 2

Quantity	Definition	Symbol	SI unit	Method of measuring	Variation with location
mass					
weight					

9. Copy **Table 3** and complete it for a 57 kg object on each planet. T/I

Table 3

Planet	Weight (N)	$\vec{g}$ (N/kg)
Mercury	188	
Venus	462	
Jupiter		26

10. A 24 kg object sits on top of a scale calibrated in newtons. Determine the reading on the scale if
    (a) the object is at rest and no one is pushing on it
    (b) the object is at rest and someone is pushing on it with a force of 52 N [down]
    (c) the object is at rest and someone is pulling on it with a force of 74 N [up] T/I

Sec. 4.1

#2, 3, 5, 7