

Above are the data generated by throwing a basket ball up in the air during the classroom demonstration, as recorded by an ultrasonic motion detector.

During time interval **A**, the ball is just resting on the box. As the ball is not changing its velocity (i.e. speed and direction of movement are constant at zero), we know it's in equilibrium and that the net force acting on the ball is zero: gravity is canceled by a support force.

During time interval **B**, the ball is being accelerated upwards by a pair of hands. The support force supplied by the hands exceeds that of gravity, thus altering the balls motion: the net force is non-zero, and pointing up-- the ball accelerates upwards. The ball is not in equilibrium.

During time interval **C**, the ball is moving upwards in the air. There is no support force on the ball as it has left the hands so the only force acting on it is gravity (ignoring air resistance). This means the net force is non-zero (in fact, it is equal to gravity!) so that the ball is not in equilibrium. The ball, though moving upwards, is accelerating downwards at a rate of 10 m/s every second, or 10 m/s^2 . This is the same thing as saying that the ball is decelerating at 10 m/s^2 . Having a velocity in the opposite direction of acceleration happens all the time-- in fact every time something slows down! A car

coming to a stop has its velocity pointing forward, while its acceleration is pointing backwards. If things could never have their velocity and accelerations pointing in opposite directions, they could never slow down.

At point **D**, the ball is momentarily stopped at its maximum height. The speed is zero. The net force is not zero, as there is still gravity acting on the ball so the ball is not in equilibrium. The acceleration is likewise non-zero: it's still 10 m/s^2 downwards. Note that it is very common to have a zero speed while having non-zero acceleration: it happens every time something starts moving from rest (e.g. a car at a stop sign). If things never could have non-zero accelerations while having zero speeds, nothing could start moving.

During time interval **E**, the ball is falling. The net force is still non-zero (it's equal to gravity), so we know that the ball is not in equilibrium. The velocity is pointing downward and it is still accelerating downward at 10 m/s^2 . Since the velocity and acceleration are pointing in the same direction, the ball is increasing its speed. This happens all the time, too: for instance when a car is speeding up on an on-ramp. If acceleration and velocity never pointed in the same direction, then nothing could ever speed up!

During time interval **F**, the ball is being caught by a pair of hands in order to slow it down. The velocity of the ball is pointing down, but it is accelerating upwards. This is because the support force of the hands exceeds the force of gravity. Since the two forces don't cancel each other out, the ball is not in equilibrium. Also, since the ball is traveling downward but accelerating upward, we know that it's decreasing its speed. Just as in **C**.

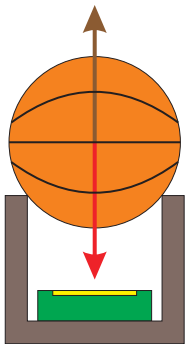
Time interval **G** is when the ball is at rest and sitting in the box again. The force of gravity is cancelled exactly by the support force of the box (the ball's not falling through the box!). Its velocity remains constant (zero). So we know that the ball is in equilibrium again, just as in **A**.

Some things to keep in mind: during **C**, **D**, **E**, the acceleration is downward and due to gravity. The ball's velocity is always changing by 10 m/s every second in the downward direction-- even during **C** (when it's velocity is upward) and at **D** (when it isn't moving at all).

When velocity and acceleration point in opposite directions, then an object is slowing down. When velocity and acceleration point in the same direction, then an object is speeding up (If velocity and acceleration point at right angles to each other, then what do you think will happen?). An object can have zero velocity but have a non-zero acceleration. In this case, an object at rest is beginning to move.

Although gravity is always acting on the ball, support forces only act on it when the ball is in contact with something (like the box or hands). When the hands release the ball, it continues to rise up in the air due to its *inertia*, and not due to an upward 'push force.'

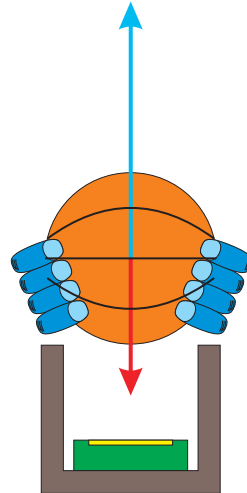
Velocity = 0 m/s
Acceleration = 0
Forces: 1) Gravity (down)
2) Support Force
from Box (up)
 $F_{\text{net}} = 0$
Equilibrium: YES



Ball Sitting
on Box

A

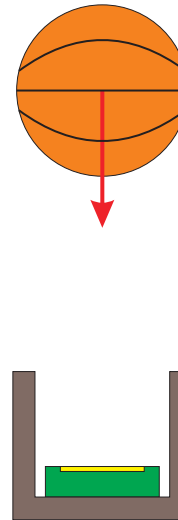
Velocity = UP; Increasing Upwards
Acceleration = UP
Forces: 1) Gravity (down)
2) Support Force
from Hands (up)
 $F_{\text{net}} = \text{UP Direction}$
Equilibrium: NO



Hands Accelerating
Ball Upwards

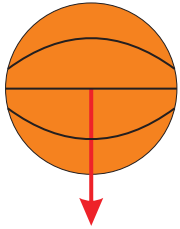
B

Velocity = UP;
Decreasing Upwards at 10 m/s
every second;
(Increasing Downwards at 10 m/s
every second)
Acceleration = DOWN (10m/s^2)
Forces: 1) Gravity (down)
(ignore air resistance)
 $F_{\text{net}} = \text{DOWN Direction}$
Equilibrium: NO

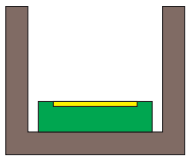


Ball Rising
Up

C



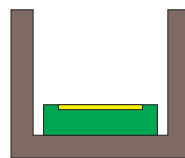
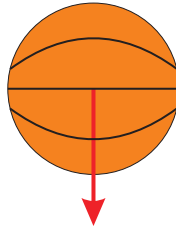
Velocity = 0;
 Decreasing Upwards at 10 m/s every second;
 (Increasing Downwards at 10 m/s every second)
 Acceleration = DOWN (10m/s^2)
 Forces: 1) Gravity (down)
 (ignore air resistance)
 $F_{\text{net}} = \text{DOWN}$ Direction
 Equilibrium: NO



Ball Sitting Still at Max. Height

D

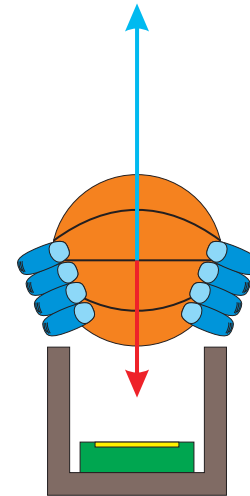
Velocity = DOWN;
 Increasing Downwards at 10 m/s every second;
 (Decreasing Upwards at 10 m/s every second)
 Acceleration = DOWN (10m/s^2)
 Forces: 1) Gravity (down)
 (ignore air resistance)
 $F_{\text{net}} = \text{DOWN}$ Direction
 Equilibrium: NO



Ball Falling Down

E

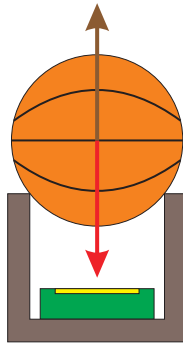
Velocity = DOWN; Increasing Upwards
 Acceleration = UP
 Forces: 1) Gravity (down)
 2) Support Force from Hands (up)
 $F_{\text{net}} = \text{UP}$ Direction
 Equilibrium: NO



Hands Catching Ball

F

Velocity = 0 m/s
Acceleration = 0
Forces: 1) Gravity (down)
2) Support Force
from Box (up)
 $F_{\text{net}} = 0$
Equilibrium: YES



Ball Sitting
on Box

G