Physics 100

Reminder:

http://www.hunter.cuny.edu/physics/courses/physics100/fall-2016

for on-line lectures

Today:

Finish Chapter 3

Chap 4 - Newton’s Second Law

In Chapter 4, we establish a relationship between **force** (chap 2) and **acceleration** (chap. 3).

Mass and Weight

- **Mass** = measure of inertia of object. Quantity of matter in the object. Denote m.

Recall: inertia measures resistance to any effort made to change its motion

- **Weight** = force upon an object due to gravity: weight = mg

Often weight and mass are used interchangeably in every-day life, but in physics, there is a fundamental difference.

- E.g. In outer space, there is no gravity so everything has zero weight. But, things still have mass. Shaking an object back and forth gives sense of how *massive* it is because you sense the inertia of it without working against gravity – horizontal changes in motion sense mass, not weight.

Mass and Weight continued

- Note mass is an *intrinsic property* of an object - e.g. it doesn't depend on where it is, whereas weight does depend on location (e.g. weight is less on moon than on earth…)

- Units:

Standard unit for mass is kilogram, kg.

Standard unit for weight is Newton (since it's a force) (commonly, pound)

Clicker Question

A 10 kg bag of rice weighs one-sixth as much on the moon than on earth because the moon's gravity is one-sixth as much as the earth's.

If you tried to slide the bag horizontally across a smooth table to a friend, is it one-sixth as easier on the moon than on earth? (ignore friction)

A) Yes

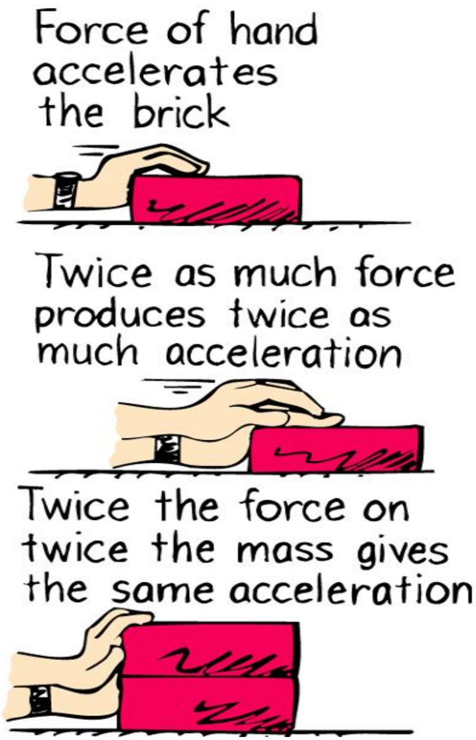
B) No

Answer: B

No! The same horizontal force is needed, since the mass (inertia) of the bag is the same.

Towards Newton's Second Law of Motion…

(i) Acceleration is created by a net force



Acceleration ~ net force

~ means, "directly proportional to"

Twice the force on same object, gives twice acceleration

Towards Newton's Second Law of Motion…

(ii) Mass resists acceleration

Acceleration ~ $\dfrac{\mathbf{1}}{\mathbf{mass}}$

Eg. The same force applied to twice the mass gives half the acceleration

Newton's Second Law

Puts (i) and (ii) together:

The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.

$$\boxed{a = \frac{F_{net}}{m}}$$

Often stated as $F_{net} = ma$

Newton's Second Law: Note about direction

An object accelerates in the direction of the net force acting on it.

• Eg. Drop a ball – it accelerates downward, as force of gravity pulls it down

• Eg. We considered last time throwing a ball upward. When the ball is thrown upward, what is the direction of its acceleration (after leaving your hand)?

Acceleration is downward (gravity) – so the ball slows down as it rises. *i.e. when force is opposite to the object's motion, it will decrease its speed*.

• When the force is at right-angles to the object's motion (eg throw ball horizontally), the object is *deflected*.

Recall Free-fall: when $a = g$

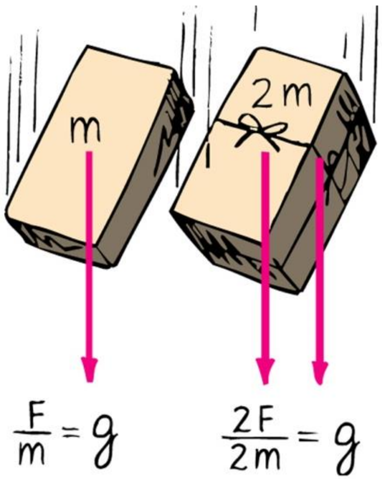
Recall last time: when the force of gravity is the only force (negligible air resistance), then the object is in “free-fall”.

Question

Since weight = mg = force of gravity on an object, heavier objects experience more gravitational force – so why don’t they fall faster than lighter ones ?

Answer: The acceleration depends both on the force and the mass -- heavier objects also have a greater inertia (resistance to acceleration), a larger mass. In fact mass cancels out of t equation:

$$a = F/m = mg/m = g$$



So all objects free-fall at the same rate, *g*.

Clicker Question

In a vacuum, a coin and feather fall side by side, at the same rate. Is it true to say that, in vacuum, equal forces of gravity act on both the coin and the feather?

A) Yes

B) No

C) There is no gravity inside vacuum

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A) Yes

B) No

C) There is no gravity inside vacuum

Answer: B

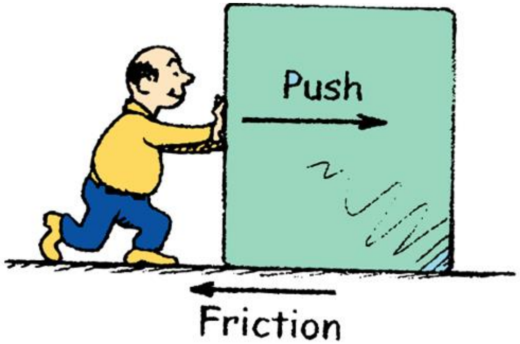
NO! They accelerate together because the ratio weight/mass for each are equal (=g). There is a greater force of gravity on the coin, but its mass (inertia) is greater too.

Friction

- When surfaces slide or tend to slide over one another, a force of friction resists the motion. Due to irregularities (microscopic bumps, points etc) in the surfaces.

  Friction also occurs with liquids and gases – eg. air drag

Eg. Push a box across a floor, applying a small steady force. The box may not accelerate because of the force of friction – it may go at constant speed, or slow down, if you get tired and start pushing less. Only if you increase your force so that it is greater than the frictional force, will the box speed up.



Friction…

- The size of the friction force between solid surfaces does not depend on speed; nor, interestingly, on the area of contact. It does depend on the object's *weight.*

- Air drag does depend on contact surface area and speed *(more soon).*

Exactly how friction works is still an active research area today!

- Consider now the box at rest.

  - Just sitting there, there is no friction.

  - If push it, but not hard enough, so it stays at rest, then the size of the friction force must exactly equal (cancel) the size of the pushing force. Why?

zero acceleration means zero net force

A little more on friction between solid-surfaces (non-examinable)…

Push a bit harder but it still won't move, the friction increases to exactly oppose it. Called "**static friction**" since nothing moves.

- There is a max. static friction force between any two objects, such that if your push is just greater than this, it will slide.

- Then, while it is sliding as you are pushing it, the friction becomes "**sliding friction**" (which is actually less than the friction that was just built up before it started moving).

- That static friction > sliding friction is important in anti-lock breaking systems in cars (see your book for more on this)

Question

The captain of a high-flying airplane announces that the plane is flying at a constant 900 km/h and the thrust of the engines is a constant 80 000 N.

a) What is the acceleration of the airplane?

Zero, because velocity is constant

b) What is the combined force of air resistance that acts all over the plane's outside surface?

80 000 N.

Since, if it were less, the plane would speed up; if it were more, the plane would slow down. Any net force produces an acceleration.

c) Now consider take-off. Neglecting air resistance, calculate the plane's acceleration if its mass is 30 000 kg, and the thrust at take-off is 120 000 N.

$a = F/m = (120\ 000\ \text{N})/(30\ 000\ \text{kg}) = 4\ \text{m/s}^2$

“Non-Free” Fall: accounting for air resistance

A feather and a coin do *not* fall at the same rate in air because of air resistance, (a.k.a. air drag).

Let’s begin with a little demo:

(i) Drop a piece of paper - as it falls, it flutters, moves sideways due to air resistance.

(ii) Crumple paper into ball – it falls faster, less air resistance because of less surface area (see more shortly)

(iii) Drop book and paper side by side – book falls faster, due to greater weight c.f. air drag

(iv) Place paper on lower surface of book and drop – they fall together.

(v) Place paper on upper surface of book and drop – what happens?? They fall *together!!* The book “plows through the air” leaving an air resistance free path for paper to follow.

More details…

- Newton's Laws still apply: in addition to force of gravity, have force of air drag, *R* – due to air molecules bouncing off surface of object, slowing it down

- So acceleration = Net Force/mass is less than in vacuum, since

  Fnet = weight (down) – air drag (up)

  $= mg - R$

- *R* depends on

(i) the **frontal area** of the falling object – the amount of air the object must "plow" at each instant

(ii) the **speed** of the falling object – the faster, the more air molecules encountered each second

- So the air drag force on an object dropped from rest starts at zero, and then increases as object accelerates downward -- until terminal speed (see shortly) at which R = mg.

- Our paper and book demo –

Both had about the same frontal area, but since the weight of the paper < weight of book, the (increasing) air drag *R* soon cancels the downward acting weight, sooner for the paper since it weighs less.

Then the net force is zero, $R=mg$, and it no longer accelerates – it goes at constant **terminal speed** (or **terminal velocity**) after this.

On the other hand, the book continues to gain speed, until its larger weight equals R, and then it too will go at its terminal speed, higher since it accelerated for longer.

- The same idea applies to all objects falling in air

e.g. Skydiver, speeds up initially, and so the air drag force *R* increases, but is still less than the weight. Eventually a speed is reached that *R* equals the weight, after which no more speed gain –i.e. terminal speed.

- Note also that effect of air drag may not be noticeable when dropped from shorter heights, since speeds gained are not as much, so air drag force is small c.f. weight.

Eg: Terminal speeds:

Skydiver ~ 200 km/h

Baseball ~ 150 km/h (or, 95 mi/h)

Ping-pong ball ~ 32 km/h (or, 20 mi/h)

Feather ~ few cm/s

Question: How can a skydiver decrease his terminal speed during fall?

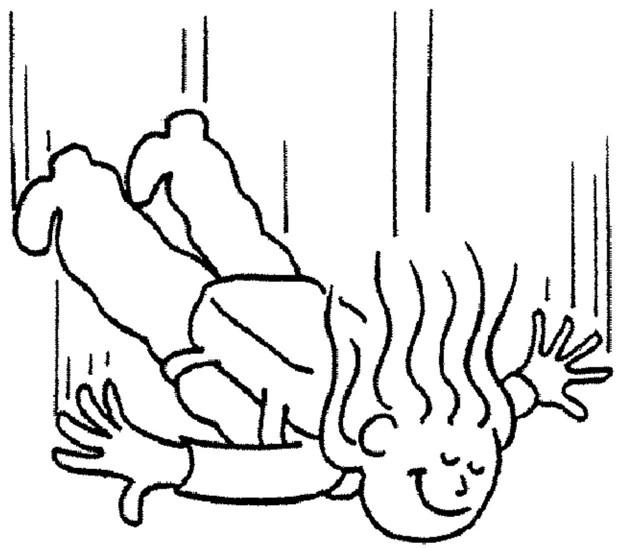
Answer: By spreading out (increase frontal area)

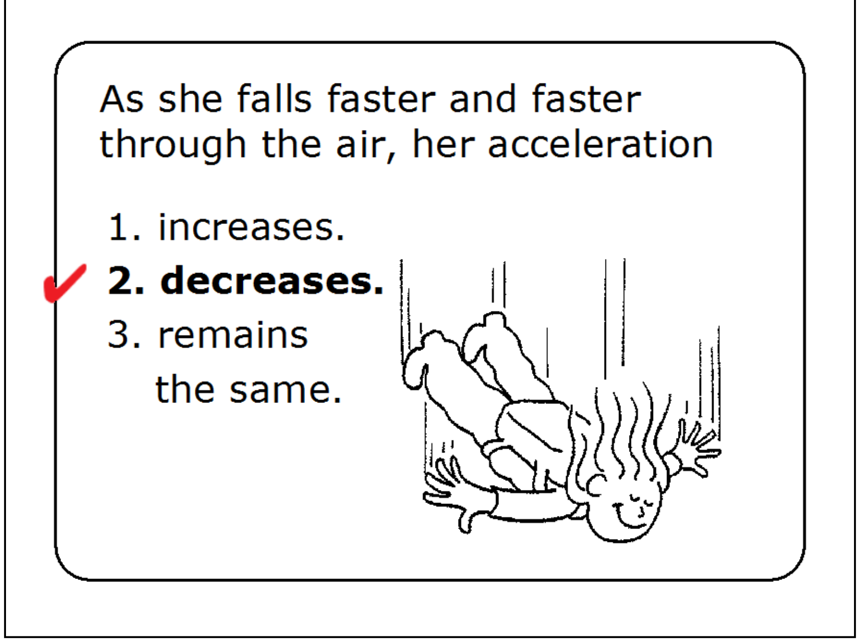
i.e. make body horizontal with arms and legs spread out

Clicker Question

As she falls faster and faster through the air, her acceleration

1. increases.
2. decreases.
3. remains the same.





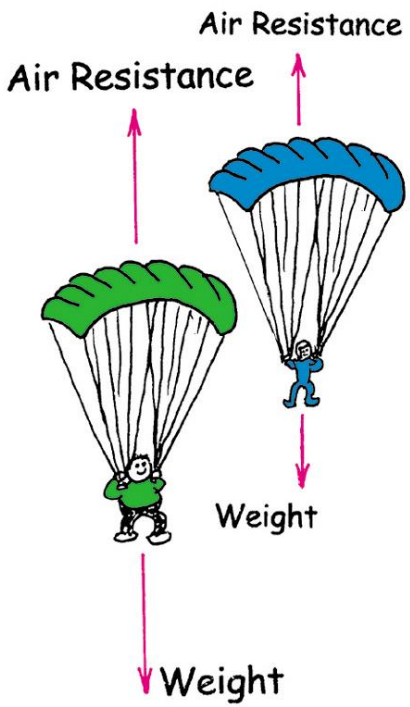
Answer: Acceleration decreases because the net force on her decreases. Net force is equal to her weight minus her air resistance, and since air resistance increases with increasing speed, net force and hence acceleration decreases. By Newton’s 2nd law,

,

$$a = \frac{F_{\text{net}}}{m} = \frac{(mg - R)}{m}$$

where *mg* is her weight and *R* is the air resistance she encounters. As *R* increases, *a* decreases. Note that if she falls fast enough so that *R* = *mg*, *a* = 0, then with no acceleration she falls at constant velocity.

Eg. Two parachuters, green man heavier than blue man, each with the same size of chute. Let's ask a series of questions:



(1)First ask, if there was no air resistance, who would get to ground first?

Both at the same time.

(2) They both begin to fall together in the first few moments. For which is the air drag force greater?

R depends on area – same for each, and speed – same for each. So *initially* both experience the *same drag force R*

(3) Who attains terminal velocity first? i.e. who stops accelerating first?

When *R* becomes equal to the weight, then there is zero net force. Since blue's weight is less, blue attains terminal velocity first.

(Note that as they accelerate, *R* increases, because speed increases but after terminal speed reached, *R* is const.)

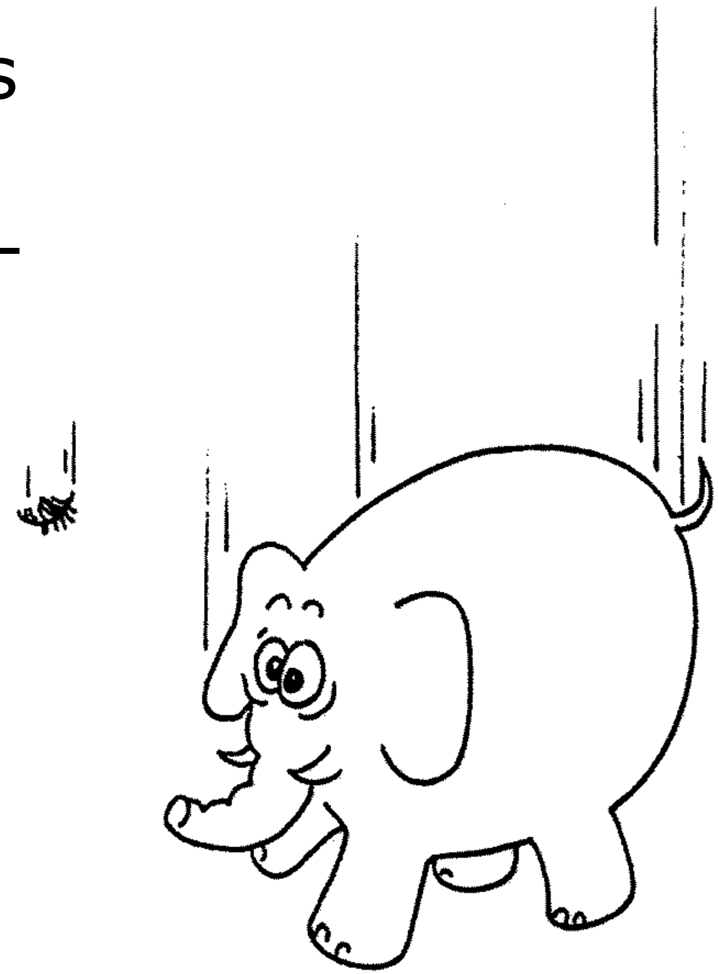
(4) Who has larger terminal veloc so who reaches ground first?

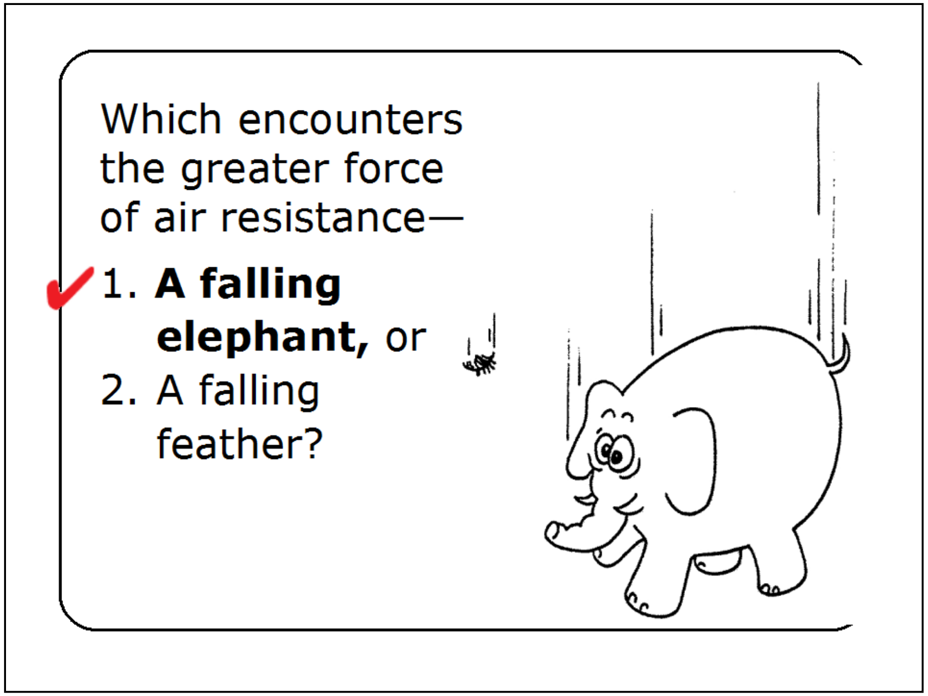
Green, he reaches his terminal velocity later, after acc. longer, so is faster…

Clicker Question

Which encounters the greater force of air resistance—

1. A falling elephant, or
2. A falling feather?



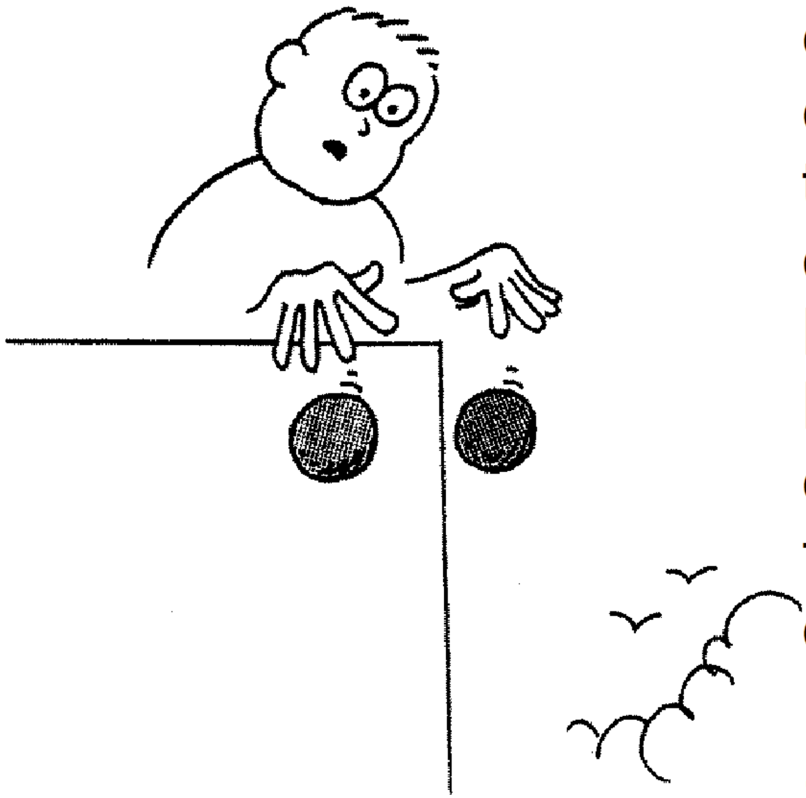


Answer: the elephant

There is a greater force of air resistance on the falling elephant, which "plows through" more air than the feather in getting to the ground. The elephant encounters several newtons of air resistance, which compared to its huge weight has practically no effect on its rate of fall. Only a small fraction of a newton acts on the feather, but the effect is significant because the feather weighs only a fraction of a newton. The elephant has larger acceleration.

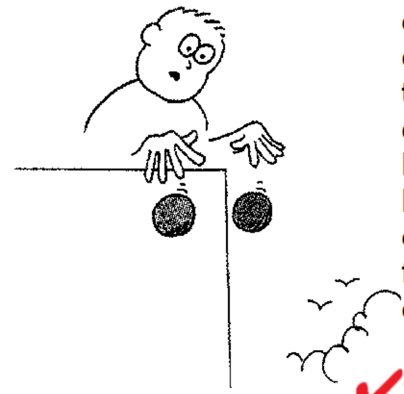
Remember to distinguish between a force itself and the effect it produces!

Clicker Question



Two smooth balls of exactly the same size, one made of wood and the other of iron, are dropped from a high building to the ground below. The ball to encounter the greater force of air resistance on the way down is

1. the wooden ball.
2. the iron ball.
3. Neither. The force is the same.



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1. the wooden ball.
2. **the iron ball.**
3. Neither. The force is the same.

Answer: the iron ball

Air resistance depends on both the size and *speed* of a falling object. Both balls have the same size, but the heavier iron ball *falls faster* through the air and encounters *greater air resistance* in its fall.

Be careful to distinguish between the *amount* of air drag and the *effect* of that air drag. If the greater air drag on the faster ball is small compared to the weight of the ball, it won't be very effective in reducing acceleration. For example, 2 newtons of air drag on a 20-newton ball has less effect on fall than 1 newton of air drag on a 2-newton ball.