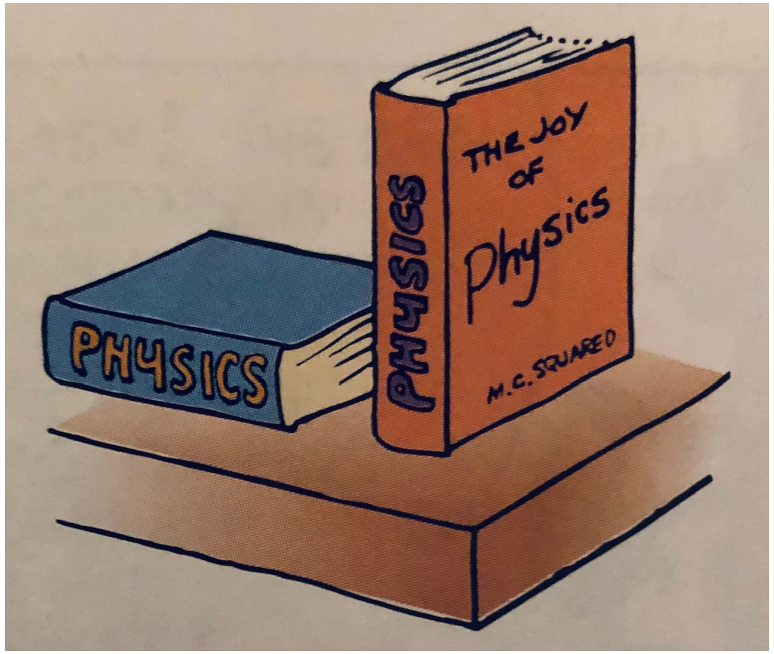
Conceptual Physics I
Classical Mechanics

Lesson 4B – Pressure, Free Fall, and Air Resistance

Pressure is the notion of a force applied over an area.

$$pressure = \frac{force}{area\ of\ application}$$



Both of these books exert the same force on the table (equal to its weight), but the upright book exerts a greater *pressure* because the contact area is smaller.

The unit for pressure will be the unit for force divided by the unit for area.

$$[pressure] = \frac{[force]}{[area]} = \frac{N}{m^2} = \text{Pascals}$$

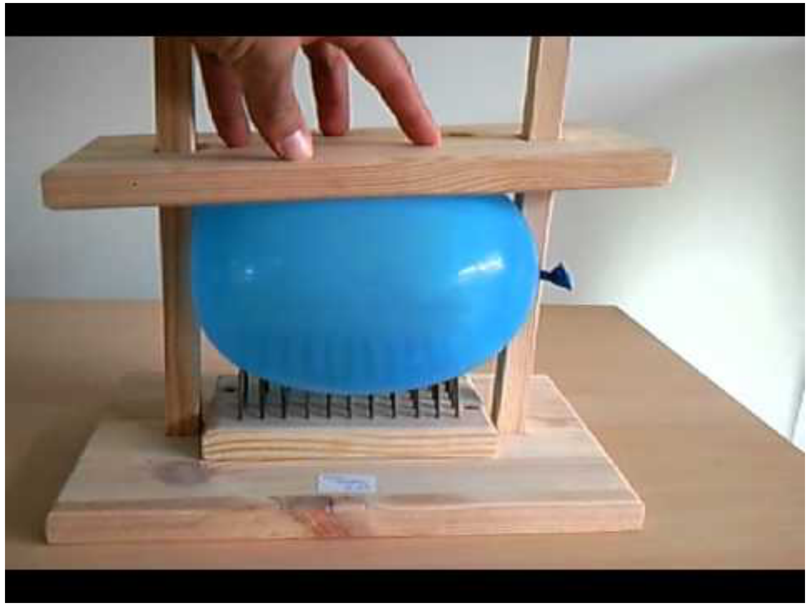
1 Newton per meter squared equals 1 Pascal (Pa)

Notes about pressure

1) You exert more pressure against the ground when you stand on one foot than when you stand on both feet.

Notes about pressure

2) Consider the famous "bed of nails" demonstration.



Significant force can be applied as the hand pushes down on the board, yet the balloon does not break. The force is distributed over numerous nails which provide a large surface area so that no nail has enough force to puncture the balloon.

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The same reasoning behind why a person breaking a cinderblock on top of another person lying on a bed of nails is not punctured.

Large number of nails = large surface area = small pressure

Questions:

1) In attempting to do the bed of nails with the person lying on top, would it be wise to begin with a few nails and work upward to more nails?

No. The pressure would be much greater and would cause harm.

Questions:

2) The massiveness of the cement block plays an important role in this demonstration. Which provides more safety, a less massive block or a more massive one?

The greater the mass of the cement block, the smaller its acceleration. In this demonstration, it is important that the block take the brunt of the force and actually break on impact!

Questions:

3) Distinguish between force and pressure.

Pressure is force exerted over an area.

4) Which produces more pressure on the ground, a person standing up or the same person lying down?

Person standing up

Questions:

5) Why does a sharp knife cut better than a dull knife?

More pressure when the cutting surface is smaller with a sharp knife.

Free Fall

- Galileo showed that falling object accelerate at the same value, regardless of their masses.
- This is strictly true if we ignore *air resistance.*
- If we consider the acceleration of an object which has only gravity acting on it, we can use Newton's Second Law to write

$$a = \frac{weight}{mass}$$

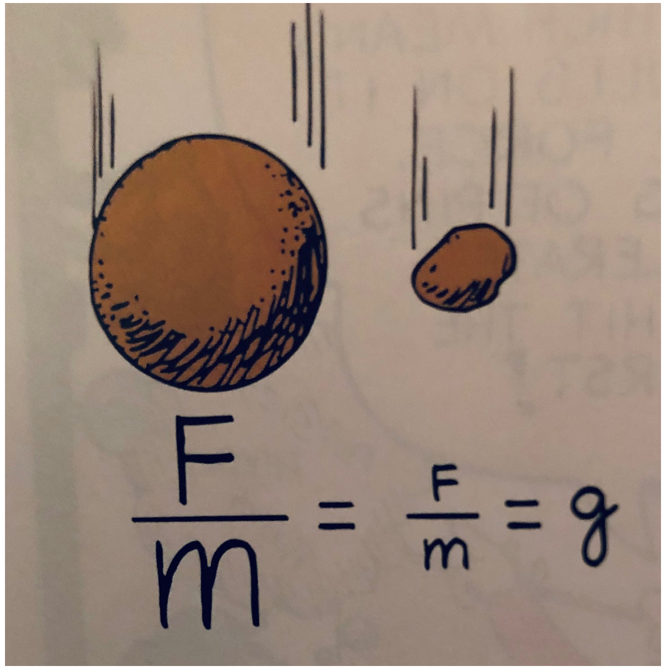
Free Fall

- An object that has a mass of 1 kg will have a free-fall acceleration of

$$a = \frac{9.8\ N}{1\ kg} = 9.8\ m/s^2$$

- An object 10 times as massive will have the same free-fall acceleration because it also is 10 times as heavy

$$a = \frac{98\ N}{10\ kg} = 9.8\ m/s^2$$



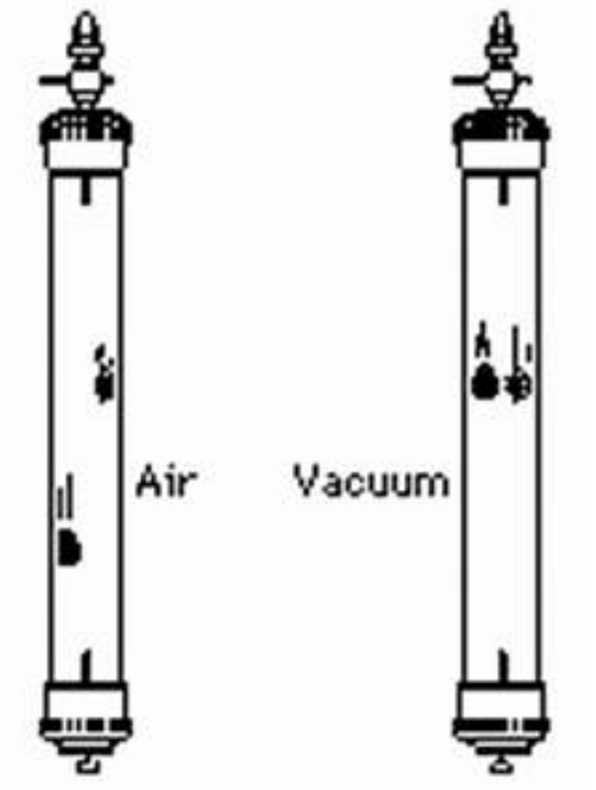
Questions

1) If you were on the moon (no air) and dropped a hammer and a feather from the same elevation at the same time, would they strike the surface of the moon at the same instant?

Yes. On the moon, the hammer and feather weigh only 1/6 of their Earth weights, and there is no air friction. They both accelerate at 1/6 x 9.8 m/s^2

Falling and Air Resistance

- A feather and a coin fall with equal accelerations in a vacuum (no air) but quite unequally in the presence of air; we would observe a coin fall quickly and the feather flutter down.
- The downward acceleration for the feather is very brief because the air resistance builds up quickly and counteracts its tiny weight.
- When the air resistance on the feather equals the weight of the feather, the net force is zero, and there is no acceleration.



Falling and Air Resistance

- When a falling object stops acceleration, we say it has reached *terminal velocity.*
- The terminal velocity for a sky diver varies from about 150 to 200 km/h, depending on the weight and orientation of the sky diver.
- A heavier person will attain a greater terminal speed than a lighter person.
- Air resistance is proportional to the speed of the falling object (even proportional to the speed squared, depending on turbulence). This means that the faster the object is falling, the greater the air resistance.

Falling and Air Resistance

- More air is encountered when the body is spread out and surface area is increased.
- If a heavy sky diver spreads out and a light sky diver falls head first, they can remain in close proximity to each other.
- A parachute greatly increases air resistance and cuts the terminal speed down to 15 to 25 km/h, slow enough for a safe landing.

Question:

If a heavy person and a light person open their parachutes together at the same altitude and each wears the same size parachute, who will reach the ground first?

The heavy person will reach the ground first because it takes him longer until he reaches his terminal velocity which is faster than the light person.

Question:

If the force of air resistance is the same for a falling baseball and a falling tennis ball, which will have the greater acceleration?

The baseball will have the greater acceleration. Let's say the falling tennis ball achieves its maximum air resistance at terminal velocity, and now say that same quantity of air resistance force is applied to the baseball which has the heavier weight. The baseball will still be accelerating because it didn't have enough air resistance to achieve terminal velocity. Get it?

Question:

How much air resistance acts on a 100-N bag of nails that falls at its terminal speed?

100 N of air resistance

Question:

What is the net force acting on a 25-N freely falling object? 25 N

What is the net force when the object encounters 15 N of air resistance? 10 N

What is the net force when it falls fast enough to encounter 25 N of air resistance? 0 N

Question:

An aircraft gains speed during takeoff due to the constant thrust of its engines. When is the acceleration during takeoff greatest – at the beginning of the run along the runway or just before the aircraft lifts into the air?

At the beginning of the run when there is little air resistance.

Question:

As a sky diver falls faster and faster through the air (before reaching terminal speed), does the net force on her increase, decrease, or remain the same? Decrease due to the increased upward force of air resistance.

Does her acceleration increase, decrease, or remain the same? Decrease due to getting closer to terminal speed.

Question:

After she jumps, a sky diver reaches terminal speed after 10 seconds. Does she gain more speed during the first second of fall or the ninth second of fall? During the first second of fall. Compared with the first second of fall, does she fall a greater or a lesser distance during the ninth second? She falls a greater distance during the ninth second because of the greater velocity.

Question: (back to Newton's Second Law)

If a loaded truck that can accelerate at 1 m/s^2 loses its load and has ¾ of the original mass, what acceleration can it attain from the same driving force?

Easy to do this with ratios. $F_i = m_i a_i; F_f = m_f a_f$

$$\frac{F_f}{F_i} = \frac{m_f a_f}{m_i a_i} \rightarrow 1 = \frac{3}{4} \frac{a_f}{1\, m/s^2}$$

$\rightarrow a_f$=4/3 m/s^2= 1.33 m/s^2

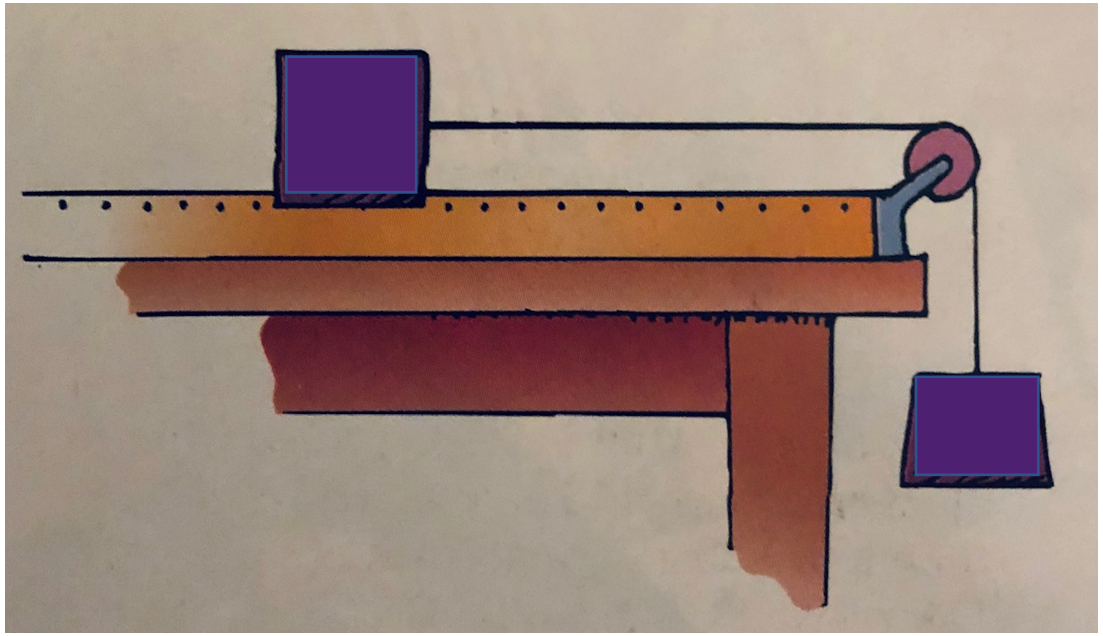
Question: (back to Newton's Second Law)

An occupant of a car has a chance of surviving a crash if the deceleration during the crash is not more than 30 g. What is the force on a 70-kg person decelerating at this rate?

$F = (70\ kg) \times (30) \times (9.8\ m/s^2) = 20{,}600\ N$

Question: (back to Newton's Second Law)

Consider two masses connected by a rope over a pulley. The top mass lies on a frictionless air track. Draw the force diagrams for each mass.



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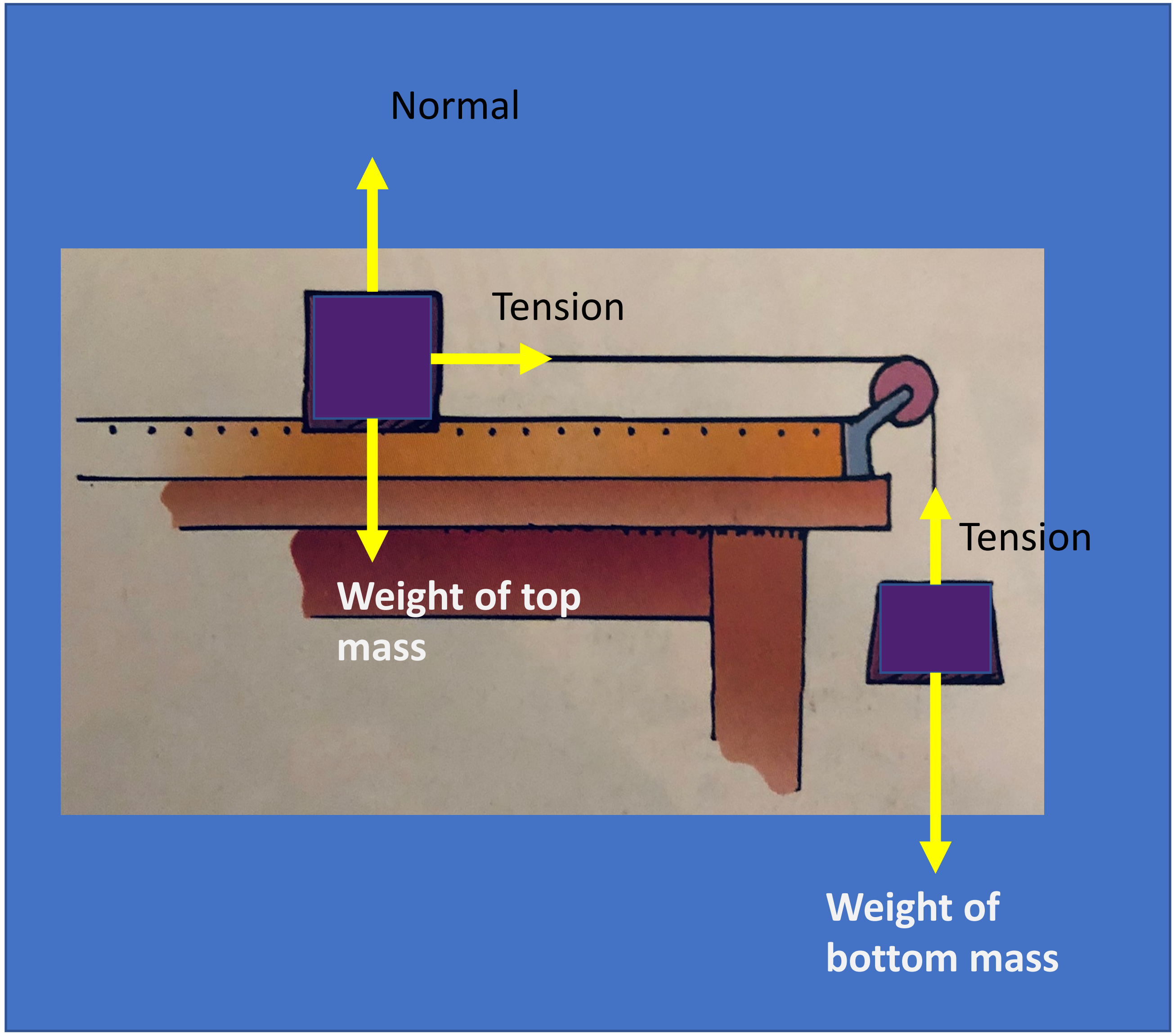

Note: Tension is the same throughout the rope; acceleration of both masses will be the same if the rope doesn't stretch.

Apply Newton's Second Law (F_{net} = ma) to each mass.

Top mass

Vertical: Normal force = Weight of top mass

Horizontal: Tension = top mass x acceleration ($T = m_{top}\ a$)

Bottom mass

Vertical: Tension – Weight of bottom mass = - bottom mass x acceleration

($T - m_{bottom}\ g = -\ m_{bottom}\ a$)

Solving: $a = \frac{m_{bottom}}{m_{bottom}+m_{top}} g$

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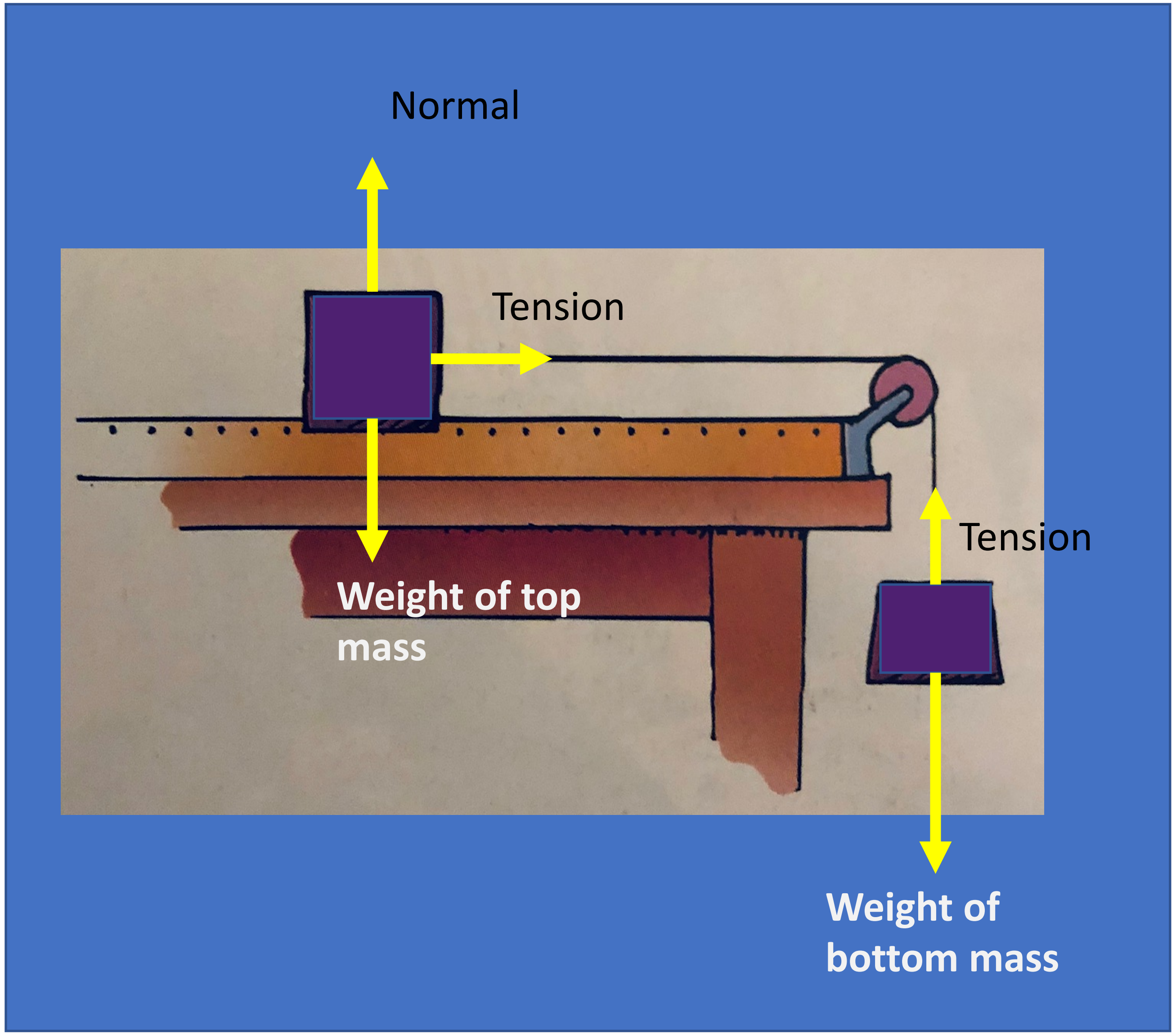

a = $\frac{m_{bottom}}{m_{bottom}+m_{top}} g$

If the masses are the same, what is the acceleration multiple of g? ½

If the bottom mass is huge compared to the top mass, what is the acceleration multiple very close to? 1

If the top mass is huge compared to the bottom mass, what is the acceleration multiple very close to? 0

What do you think the maximum acceleration of such a system of masses is? g.