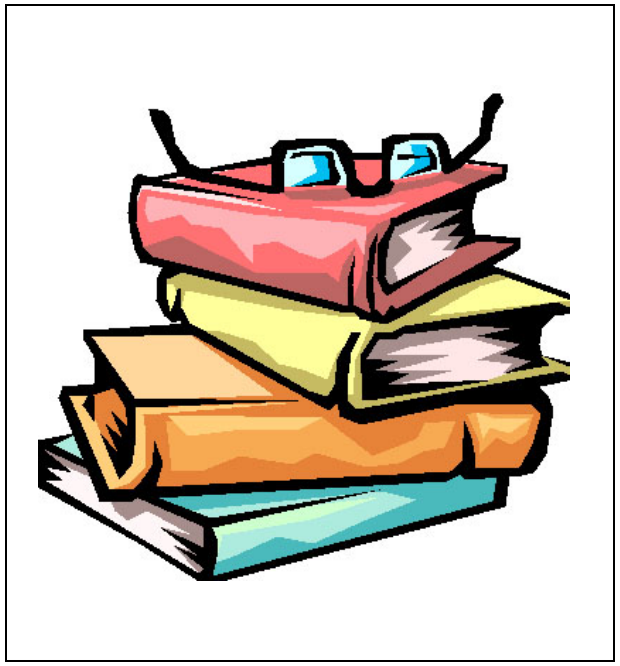
Power

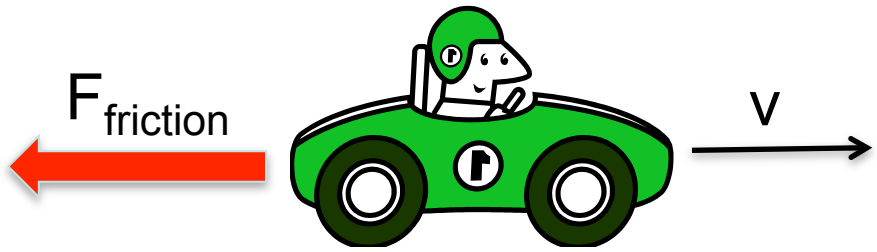
Physics 1003: Dr. Stefan Bathe



Day 10:
Power
F = ma: Car crashes
Review

Reminders:
Reading for Monday, 3/12: Section 5.2 (Water Distribution)
No office hours on Wednesday (away)

Friction and energy



- Work done by friction is always negative
  - $F_{friction}$ always opposite to direction of motion
  - Friction always takes energy away from moving object as heat
- Friction takes useful energy (motional) and turns it into heat energy (less useful) but energy is still conserved.

Energy problems

Now we can handle problems with several different kinds of work/energy

- GPE
- W_{ext} (work done by hand, rope etc attached to the object)
- $W_{friction}$

How are they all related?

⇒ By CONSERVATION OF ENERGY

Consider C of E for an object: block, car etc

$$\boxed{W_{ext} - |W_{friction}| = \Delta PE + \Delta KE}$$

Energy given by hand

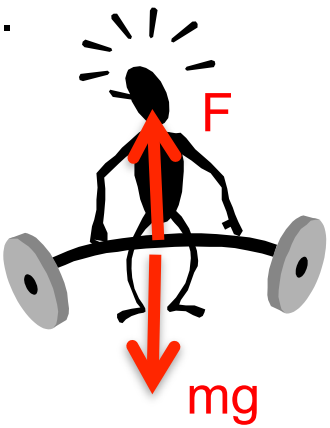
Energy taken away by friction

Change in stored energy (GPE, EPE)

Change in motional energy

Human energy

Calories are just another unit for measuring energy
1 cal = 4.184 J
1 food calorie = 1 Cal = 1 kcal = 1000*4.184 J = 4184 J.



Power

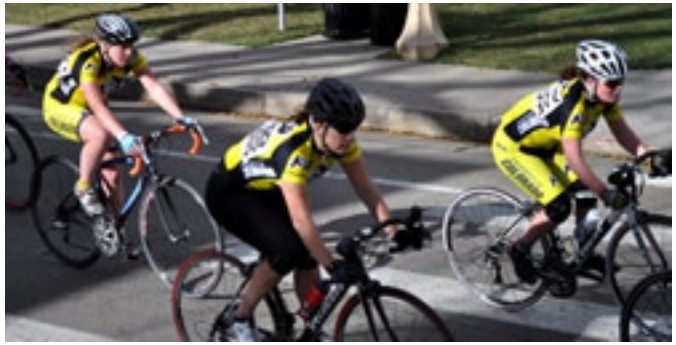
Power = Energy/time

Units: 1 watt = 1 W = 1J/s.

$\Rightarrow$ 100 watt lightbulb means 100 Joules electrical energy/sec.

Human eats 2500 Cal per day = 120 W

Easy to measure on a bicycle with a power meter!



How much of our food energy goes into useful work?

- Tour de France rider: 400 W for ~1 hour, *[~1/2 horsepower]*
- Athletic man: ~150 W on bike for 10 hour day

So if I go to the gym and pedal at 150W output, I could

a) Power the ac for the entire building
b) Power a space heater
c) Power a lightbulb
d) Power not enough to run anything of interest

How much of our food energy goes into useful work?

- How much force x distance can person do?
  ⇒ Easy to measure with stationary bicycle.
  - Tour de France rider: 400 W for ~1 hour, *[~1/2 horsepower]*
  - Athletic man: ~150 W on bike for 10 hour day

So if I go to the gym and pedal at 150W output, I could

a) Power the ac for the entire building
b) Power a space heater
c) Power a lightbulb
d) Power not enough to run anything of interest

How much of our food energy goes into useful work?

- How much force x distance can person do?
  ⇒ Easy to measure with stationary bicycle.
  - Tour de France rider: 400 W for ~1 hour, *[~1/2 horsepower]*
  - Athletic man: ~150 W on bike for 10 hour day
- How much work does he do (expressed as Cal) during 10 hour ride?

(1 Cal = 4184J)

a. 2140 Cal, b. 1290 Cal, c. 150 Cal d. 12000 Cal

How much of our food energy goes into useful work?

- How much force x distance can person do?
  ⇒ Easy to measure with stationary bicycle.
  - Tour de France rider: 400 W for ~1 hour, *[~1/2 horsepower]*
  - Athletic man: ~150 W on bike for 10 hour day

- How much work does he do (expressed as Cal) during 10 hour ride?

(1 Cal = 4184J)

a. 2140 Cal, b. 1290 Cal, c. 150 Cal d. 12000 Cal

Work (J) = (150J/s)×(60×60×10s) = 5,400,000J

$$\text{Work (Cal)} = (5400000\text{J}) \times \frac{1\text{Cal}}{4184\text{J}} = 1291\text{Cal}$$

- But he eats ~ 5800 Cal/day
  Where does the rest of the energy (5800-1291=4500 Cal) go?

a. chemical, b. sweating, c. light, d. heat, e. odor

How much of our food energy goes into useful work?

- How much force x distance can person do?
  ⇒ Easy to measure with stationary bicycle.
  - Tour de France rider: 400 W for ~1 hour, *[~1/2 horsepower]*
  - Athletic man: ~150 W on bike for 10 hour day

- How much work does he do (expressed as Cal) during 10 hour ride?

(1 Cal = 4184J)

a. 2140 Cal, b. 1290 Cal, c. 150 Cal d. 12000 Cal

Work (J) = (150J/s)×(60×60×10s) = 5,400,000J

$$\text{Work (Cal)} = (5400000\text{J}) \times \frac{1\text{Cal}}{4184\text{J}} = 1291\text{Cal}$$

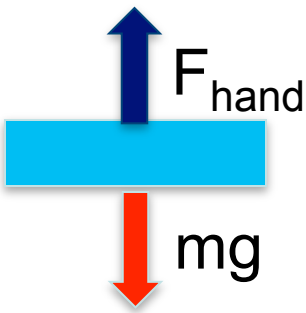
- But he eats ~ 5800 Cal/day
  Where does the rest of the energy (5800-1291=4500 Cal) go?

a. chemical, b. sweating, c. light, d. heat, e. odor

80% of our chemical energy intake is lost as heat energy
As machines we are only 20% efficient…
Similar efficiency to an internal combustion engine

Recap

Applied force is the same if book stationary or moving up/down with constant velocity (F_{hand}= weight =mg)



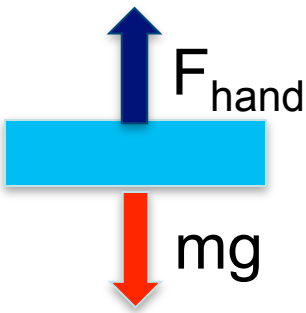
What about the amount of work done by me?

Do I do more work (get tired more quickly) lifting book up and down or just holding it up?

a. same, b. more work if lifting c. more work if holding it up

Recap

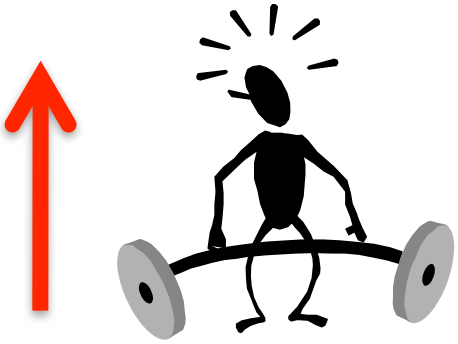
Applied force is the same if book stationary or moving up/down with constant velocity (F_{hand}= weight =mg)



What about the amount of work done by me?

Do I do more work (get tired more quickly) lifting book up and down or just holding it up?

a. same, b. more work if lifting c. more work if holding it up



Work = force x distance, only do work on weights if moving through a distance by lifting. If holding stationary then distance and work = 0.

Hard question – putting ideas so far together

I can only push with a force of 10 N, but I want to move a 3 kg mass up to a height of 0.5 m.
How steep a ramp should I make (keeping it as short as possible)?

a. can't do it, takes 29.4 N to raise a 3 kg mass.
b. a 50% grade (1m along ramp for 0.5 m up)
c. 1.5 m along ramp and 0.5 m up
d. 2 m along ramp and 0.5 m up
e. 2.5 m along ramp and 0.5 m up

Hard question – putting ideas so far together

I can only push with a force of 10 N, but I want to move a 3 kg mass up to a height of 0.5 m.
How steep a ramp should I make (keeping it as short as possible)?

a. can't do it, takes 29.4 N to raise a 3 kg mass.
b. a 50% grade (1m along ramp for 0.5 m up)
c. 1.5 m along ramp and 0.5 m up
d. 2 m along ramp and 0.5 m up
e. 2.5 m along ramp and 0.5 m up

Remember 2 new ideas:

a) Same work to go to same height (Work = mgh)
b) $W = F \times d_{//}$

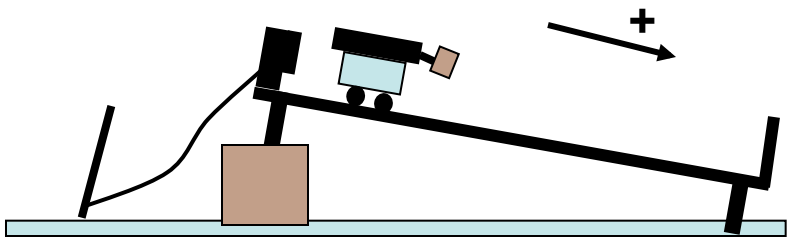
a)Imagine we lift straight up to height of 0.5m at constant speed
$W = F \times d_{//} = mg \times h = 3 \times 9.8 \times 0.5 = 15J$
This work is the same however we get the mass to height h

b) $d_{//} = W/F$
$= 15J/10N = 1.5m$

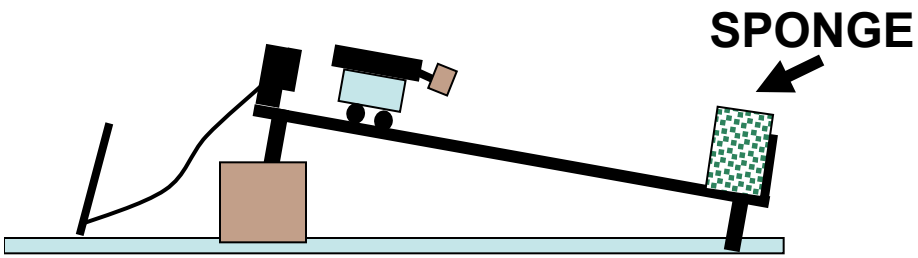
Midterm preparation

- Prepare by applying the principles we have learned – practice.
- You CANNOT memorize answers to specific questions.
- Make a formula card now with the important equations.
- Go over homeworks, class clicker questions, questions in the book.
  - Not sure how to get the answer – go to tutoring

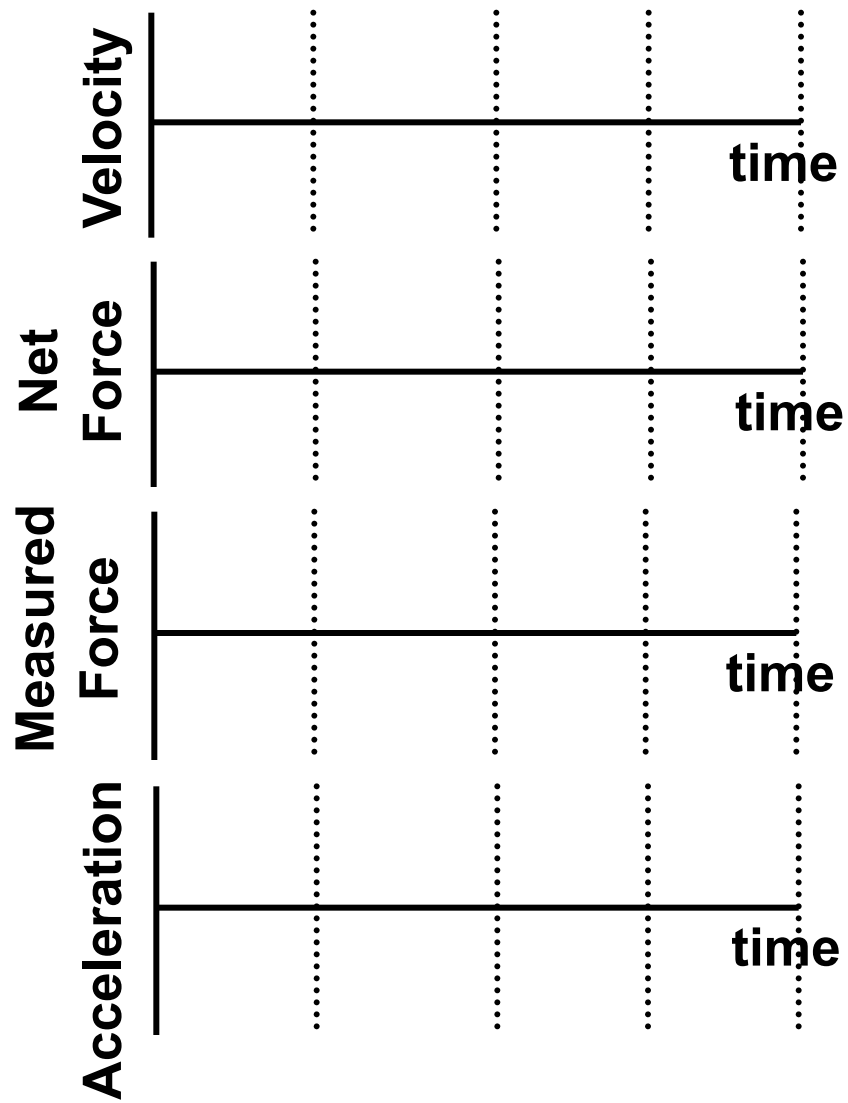
Car crashes



Case 1: hit hard end of ramp

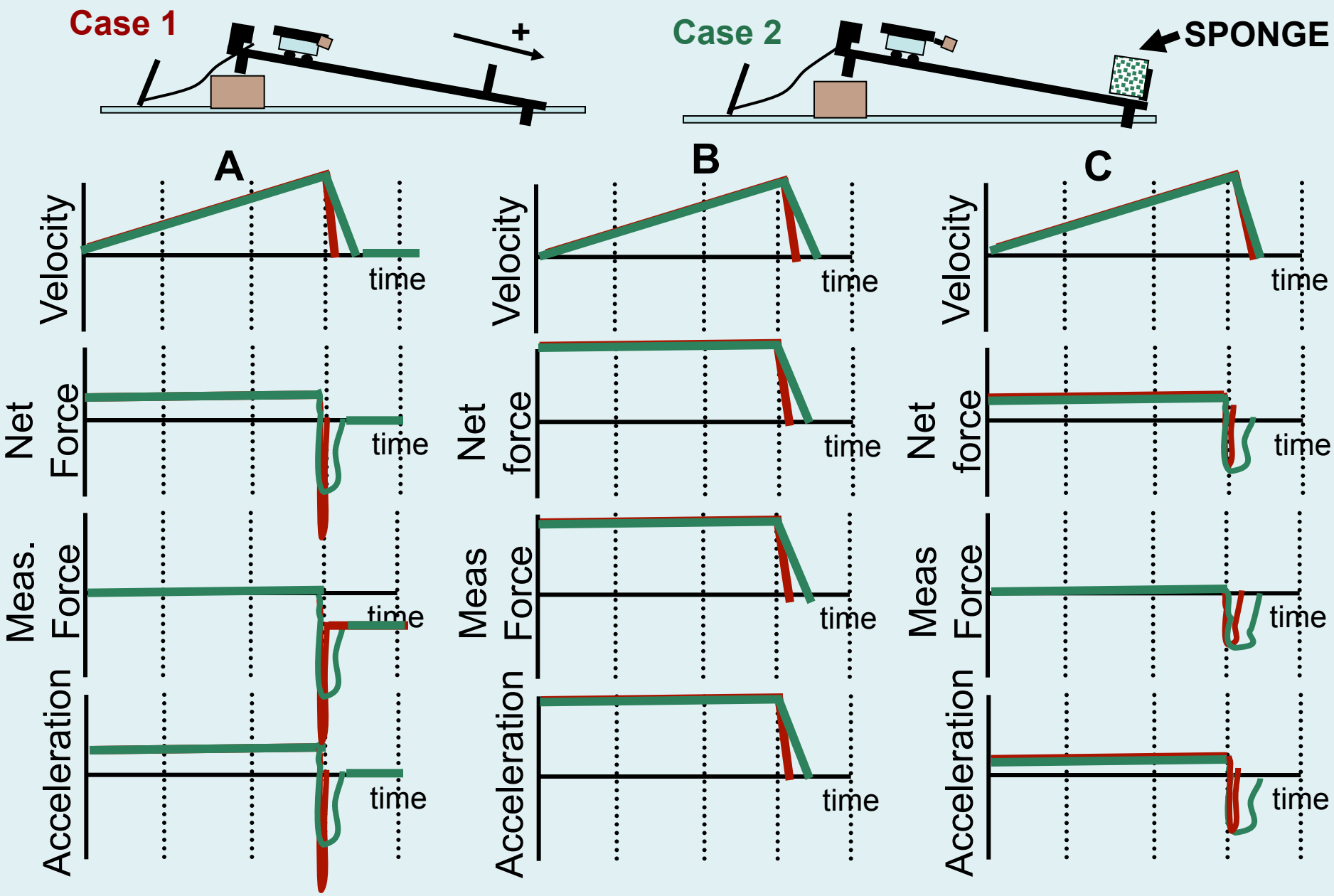


Case 2: hit sponge at end of ramp



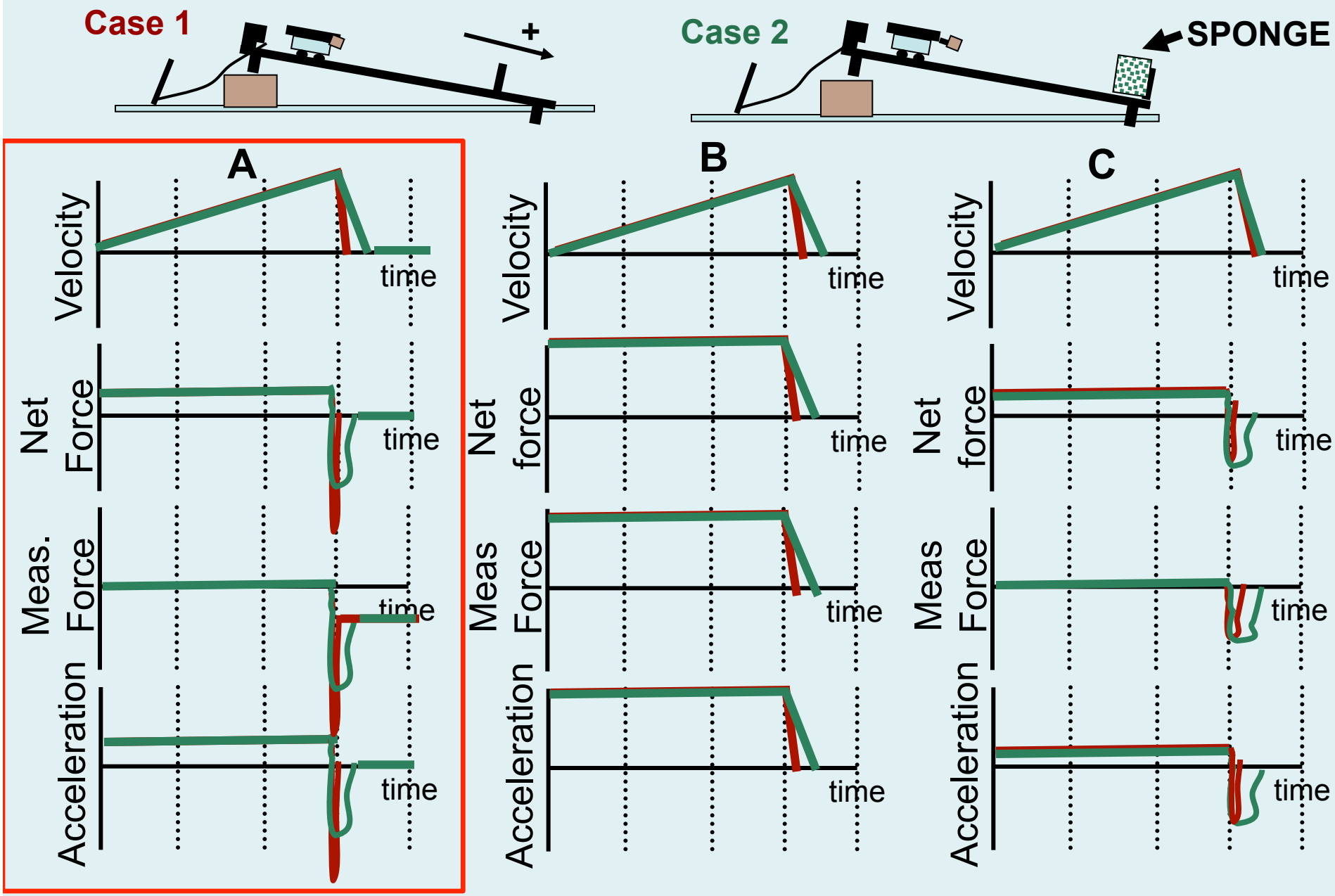
Sketch your predictions of the velocity, acceleration, net force, and measured force (by probe) vs time for this motion. Starting when we let go and ending after crash.

Plot CASE 1 AND 2 on same graph.



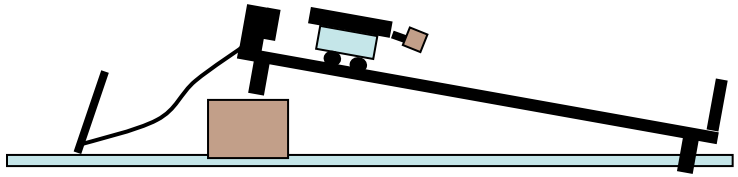
D. Same as a, but with all curves on negative side of 0 instead of positive.

E. None of these choices.

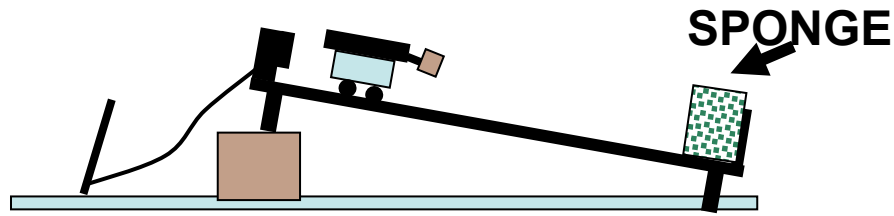


D. Same as a, but with all curves on negative side of 0 instead of positive.

E. None of these choices.



Case 1: hit hard end of ramp



Case 2: hit sponge at end of ramp

Just before crash:
All conditions for car 1 and 2 are identical
After crash:
Both car in 1 and 2 are at rest. Velocity = 0 m/s

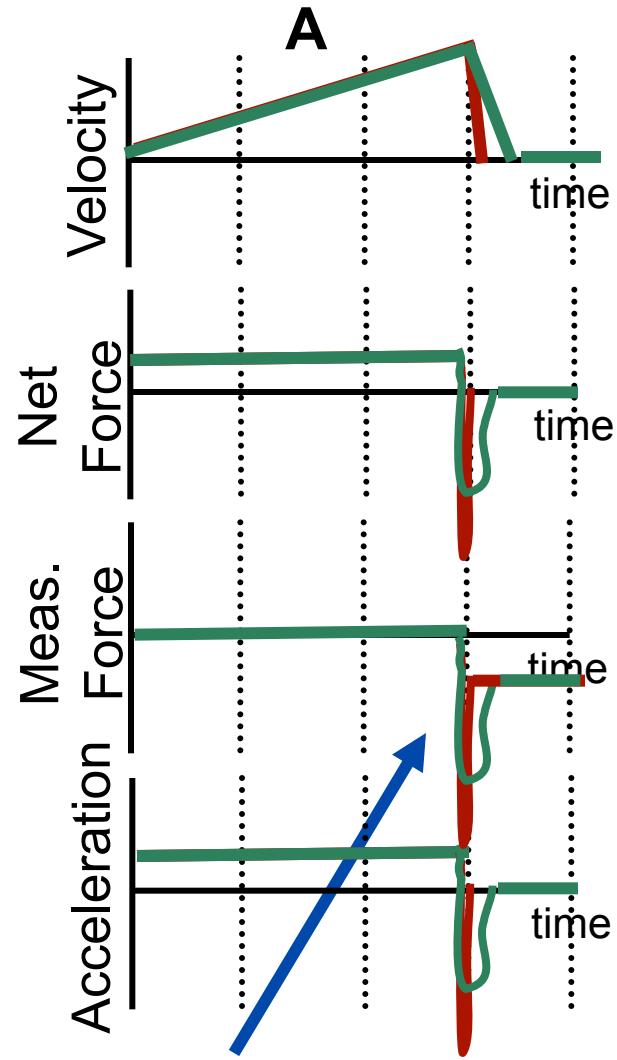
During crash: Same in both Case 1 and 2

$$\text{Acceleration during crash} = \frac{\text{change in velocity}}{\text{time elapsed during crash}}$$

Shorter in Case 1 Than Case 2

- During crash acceleration of 1 > acceleration of 2.
- $F_{net} = ma$
  $\Rightarrow$ Crash force greater on 1 … ouch!

Car safety (air bags, crumple zones etc) all designed to increase deceleration time, reduce force on humans



Wall exerts force on car.

Midterm topics - Motion

- Position, velocity and acceleration
  - Definitions, Units
  - Scalars and vectors
  - Graphs of x, v, a vs. time and relationships between graphs
  - Equations of motion and how to <u>use</u> them:

    Constant velocity: $x = x_0 + vt$

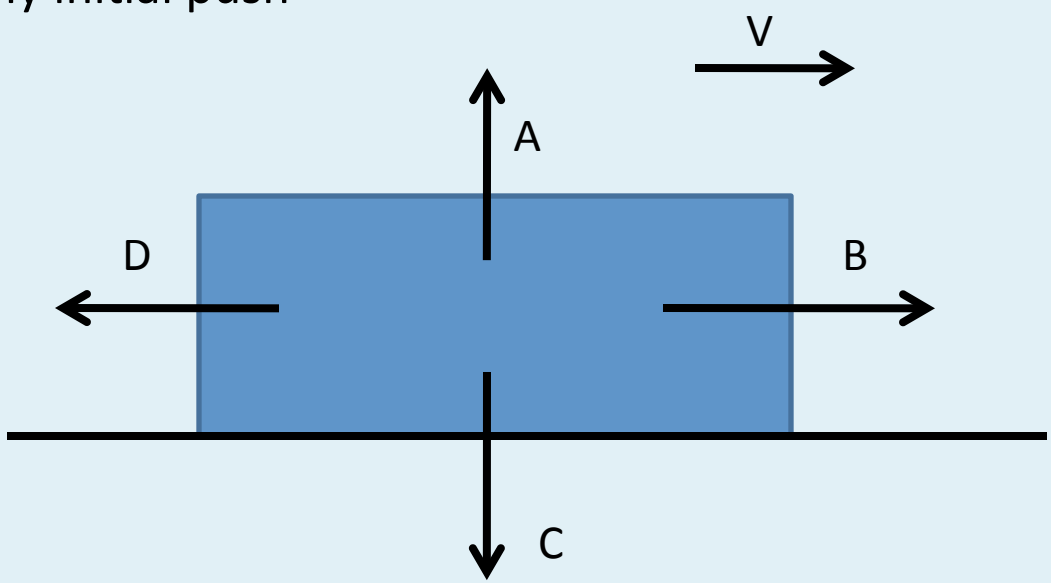
    Constant acceleration: $v = v_0 + at$

    $x = x_0 + v_0 t + \frac{1}{2} at^2$

- Forces
  - Definition, units, vector
  - $\underline{F}_{gravity} = mg$ downwards
  - $\underline{F}_{friction} \approx 0.3 \times$ weight in direction opposing motion
  - $\underline{F}_{spring} = -k\underline{x}$ in direction opposing extension/compression
  - $\underline{F}_{net} = m\underline{a} \Rightarrow$ If $a = 0$, $F_{net} = 0$
  - Free body diagrams and finding F_{net}

Motion questions

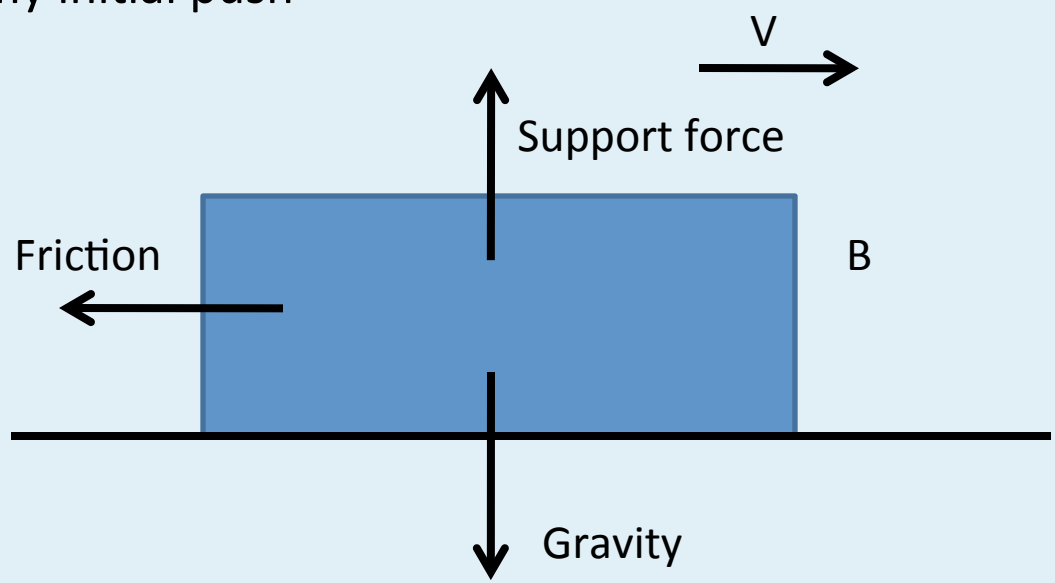
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



Which of the forces above has zero magnitude in this situation?

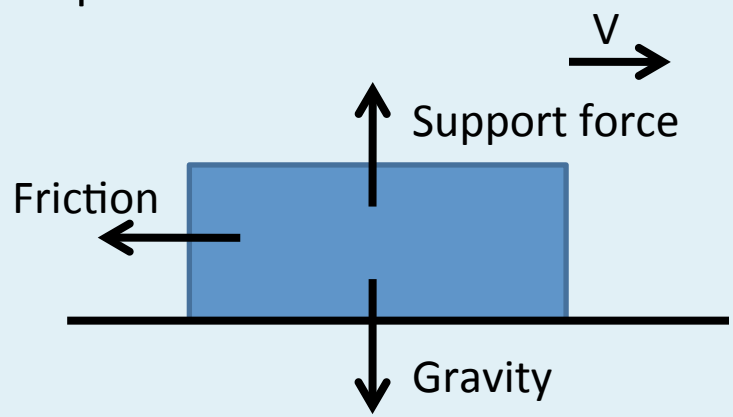
Motion questions

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



Which of the forces above has zero magnitude in this situation? B

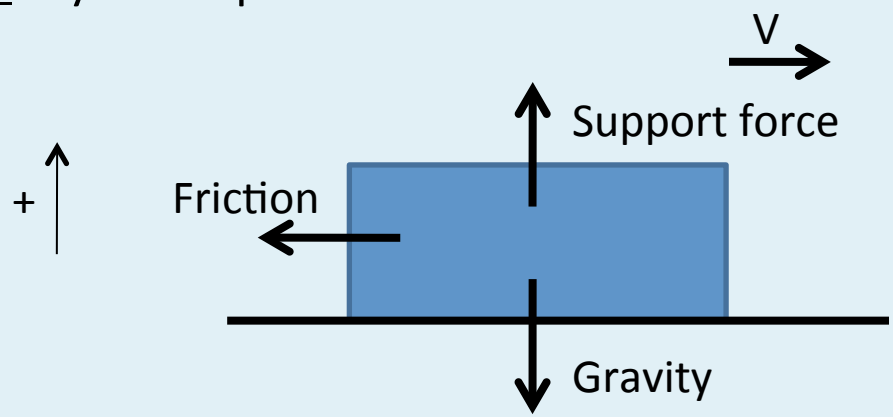
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is the approximate size of the support force?

a) 2N b) 10 N c) 20N d) 40 N e) Can't be determined

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is the approximate size of the support force?

a) 2N b) 10 N c) 20N d) 40 N e) Can't be determined

Vertical direction: $F_{net} = F_{support} - mg$

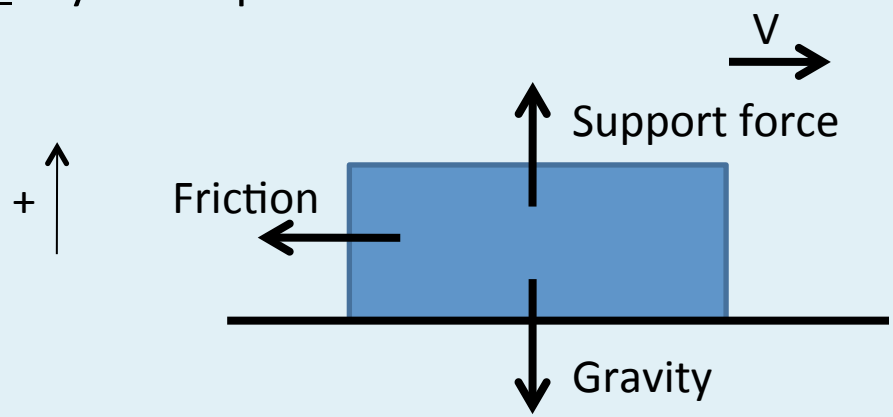
$a = 0 \Rightarrow F_{net} = 0$

$F_{support} - mg = 0$

$F_{support} = mg$

$= 2kg \times 10m/s^2 = 20N$

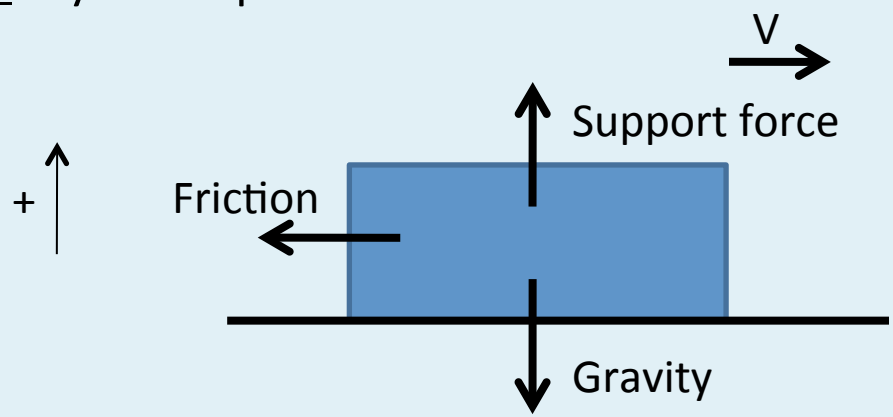
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is the approximate size of the friction force?

a) 2N b) 6 N c) 20N d) 60 N e) Can't be determined

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is the approximate size of the friction force?

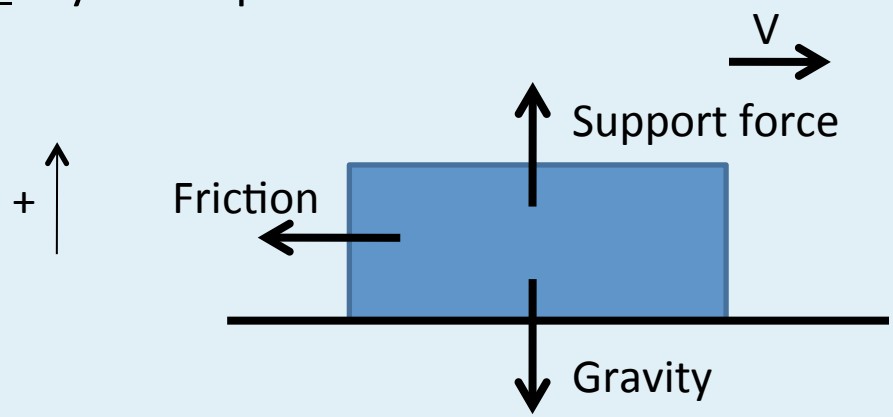
a) 2N b) 6 N c) 20N d) 60 N e) Can't be determined

Force of sliding friction $\approx 0.3 \times mg$

$\approx 0.3 \times 20N$

$\approx 6N$

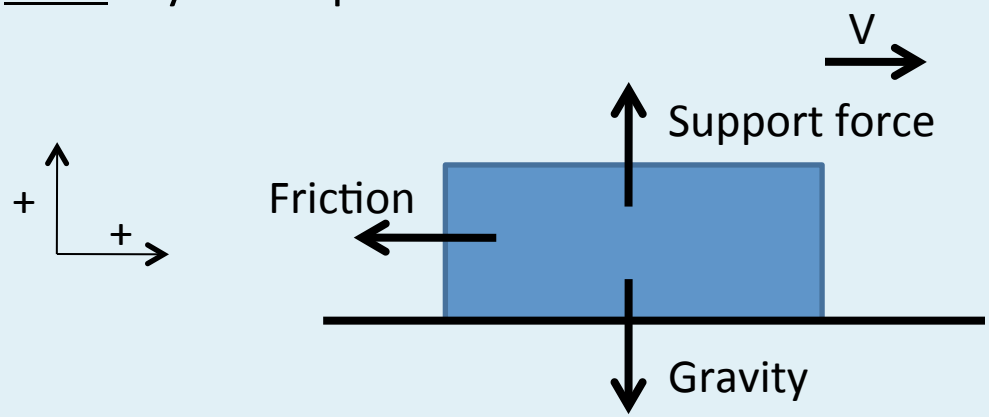
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is acceleration of the box?

a) 0 b) 6 m/s^2 c) -6 m/s^2 d) 3 m/s^2 e) -3m/s^2

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is acceleration of the box?

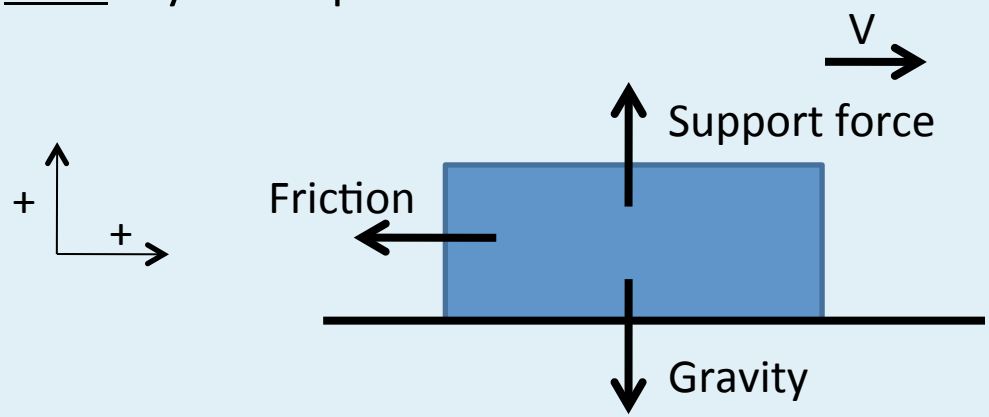
a) 0 b) 6 m/s^2 c) -6 m/s^2 d) 3 m/s^2 e) -3m/s^2

Net force = ma

$a = F_{net}/m = -6N / 2kg$

$= -3m/s^2$

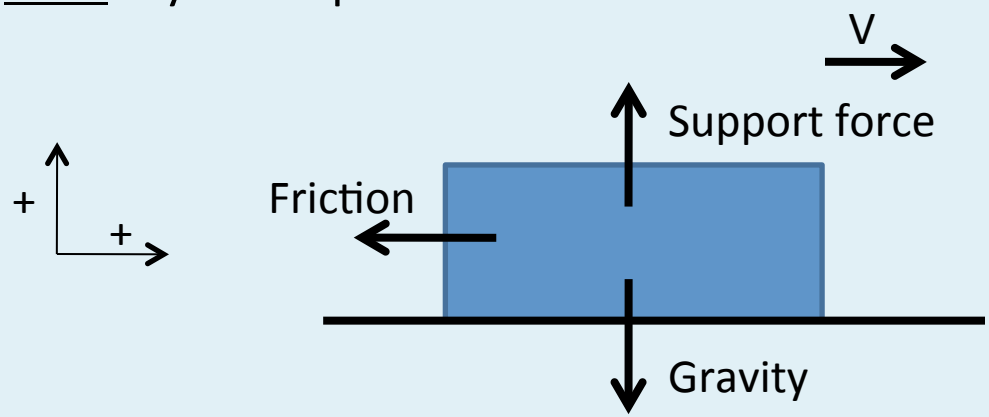
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



What is the velocity of the box after 1.5s?

a) 6m/s b) 4.5m/s c) 3m/s d) 1.5m/s e) 0

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push

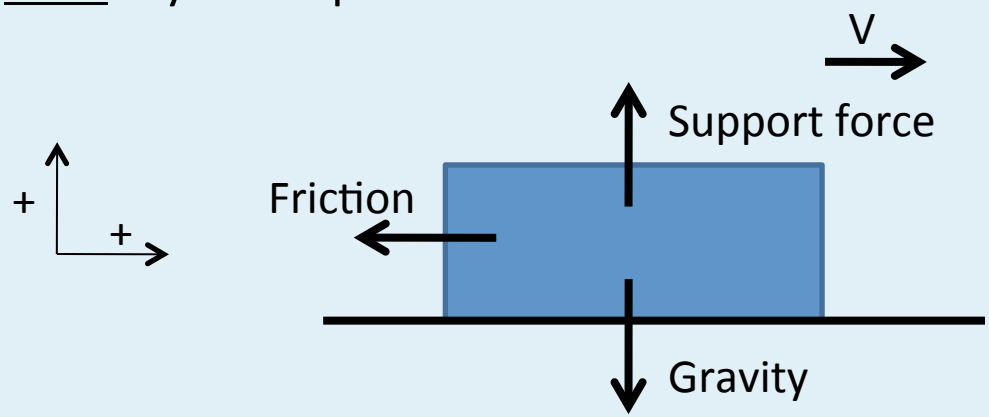


What is the velocity of the box after 1.5s?

a) 6m/s b) 4.5m/s c) 3m/s d) 1.5m/s e) 0

- We know v_0, a and t, want v
- Use $v = v_0 + at$
- $v = 6m/s + (-3m/s^2)(1.5s)$
  $= 1.5m/s$

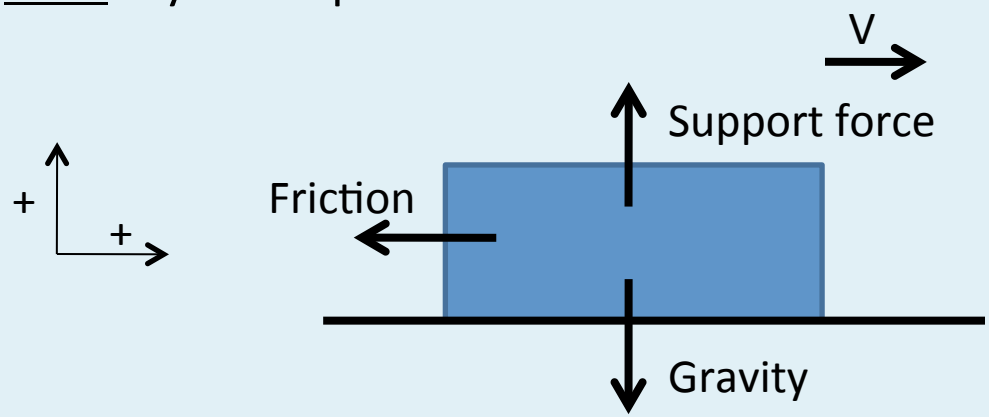
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



How long does box travel for before it stops?

a) 0s b) 0.5s c) 1s d) 1.5s e) 2s

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



How long does box travel for before it stops?

a) 0s b) 0.5s c) 1s d) 1.5s e) 2s

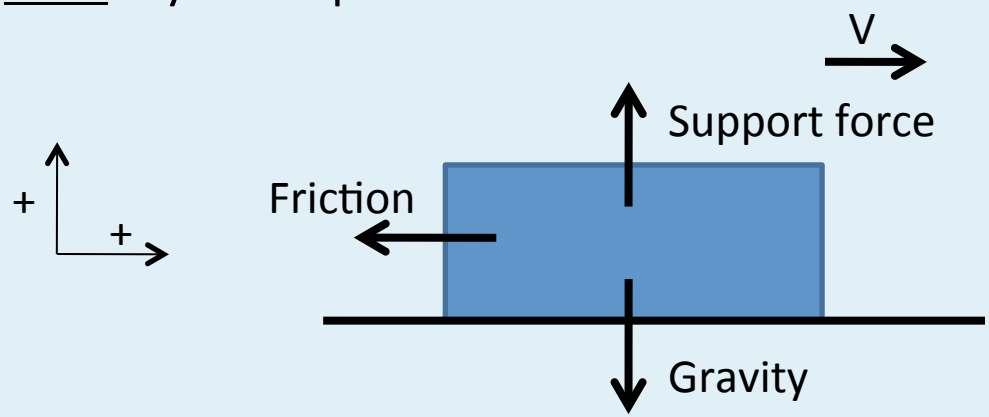
- We know v_0, a and v, want t
- Use $v = v_0 + at$
- Rearrange: $v - v_0 = at$

$(v - v_0)/a = t$

$(0 - 6m/s)/(-3m/s^2) = t$

$t = 2s$

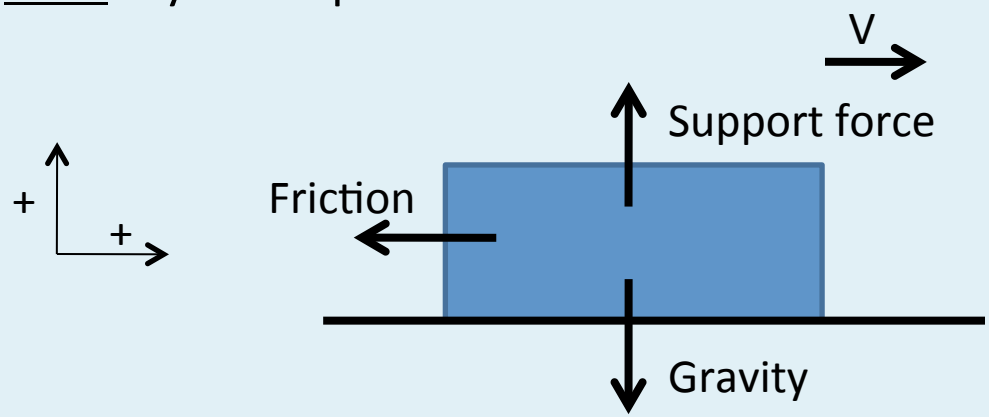
I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



How far does box travel for before it stops?

a) 0m b) 2m c) 3m d) 6m e) 12m

I push a shoebox of mass 2kg across a lino floor. I give it an initial velocity of +6m/s and after that it travels on its own. The next few questions relate to its motion <u>after</u> my initial push



How far does box travel for before it stops?

a) 0m b) 2m c) 3m d) 6m e) 12m

We know x_0, v_0, a and t and we want x.

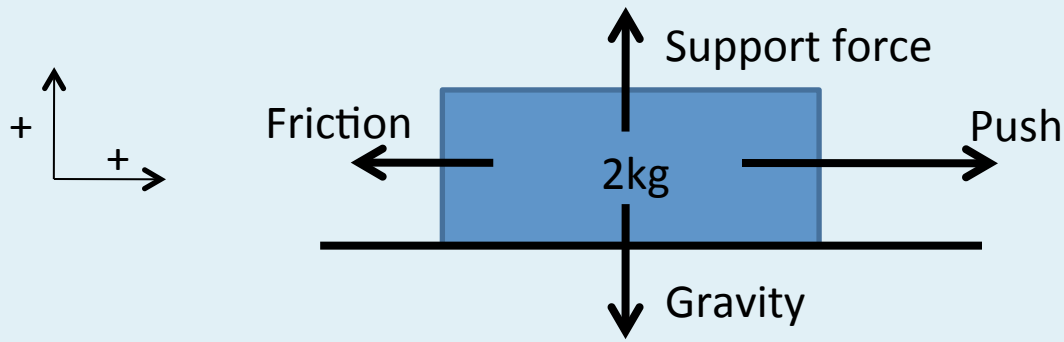
Use $x = x_0 + v_0 t + \frac{1}{2} at^2$

$x = 0 + (6)(2) + \frac{1}{2}(-3)(2^2)$

$= 12 - 6m$

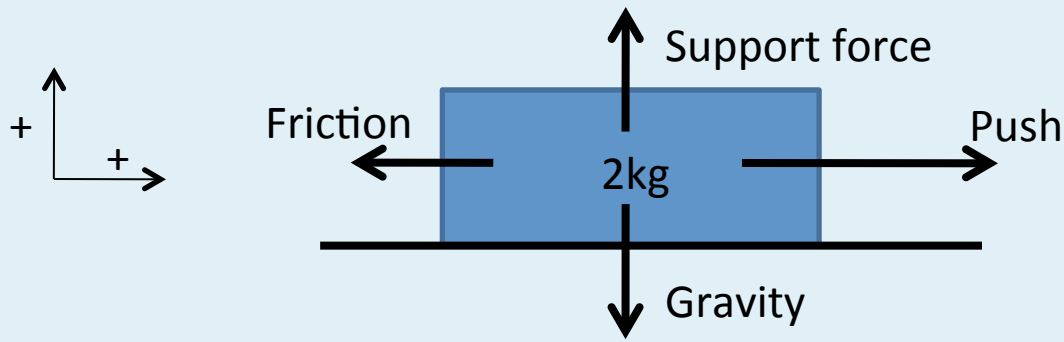
$= 6m$

The box comes to a stop. I start pushing it again, this time continuously. It accelerates at $2m/s^2$. What is the size of my horizontal pushing force? (Remember from previous questions that $F_{friction}$ = 6N when box is moving)



a) 2N b) 4N c) 6N d) 10N e) 12N

The box comes to a stop. I start pushing it again, this time continuously. It accelerates at $2m/s^2$. What is the size of my horizontal pushing force? (Remember from previous questions that $F_{friction} = 6N$ when box is moving)



a) 2N b) 4N c) 6N d) 10N e) 12N

$F_{net} = ma$

$F_{push} - F_{friction} = ma$

$F_{push} = ma + F_{friction}$

$= (2kg)(2m/s^2) + 6N$

$= 4N + 6N$

$= 10\ N$

Part of the pushing force needed to counteract friction, the rest accelerates the box

Springs

I have a spring which is labeled ‘Spring constant = 8 N/m’. I assume that this is correct and use it to measure the mass of an apple. I attach the apple to the bottom of the spring and it stretches 12.5cm. What is the mass of the apple? (assume $g = 10 m/s^2$)

a) 0.1 kg b) 1kg c) 10kg d) 100kg e) Can’t be determined.

Springs

I have a spring which is labeled 'Spring constant = 8 N/m'. I assume that this is correct and use it to measure the mass of an apple. I attach the apple to the bottom of the spring and it stretches 12.5cm. What is the mass of the apple? (assume $g = 10 m/s^2$)

a) 0.1 kg b) 1kg c) 10kg d) 100kg e) Can't be determined.

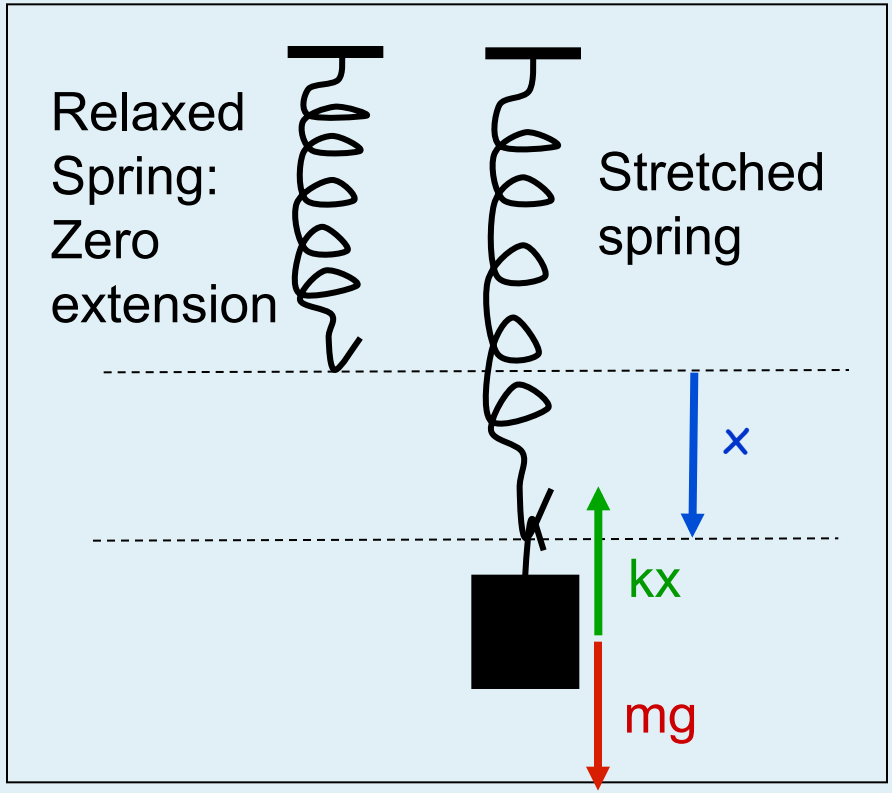
In equilibrium, net force on apple = 0. Downwards force of gravity is exactly equal and opposite to upwards force from spring.

$\Rightarrow mg = kx$

$m = kx / g$

$= (8N/m)(0.125m)/(10m/s^2)$

$= 0.1$ kg



Now I hang the same apple on a different spring and it stretches much less than 12.5cm. What is the spring constant of this spring?

a) Less than 8N/m
b) 8N/m
c) More than 8N/m
d) Can’t determine from information given

Now I hang the same apple on a different spring and it stretches much less than 12.5cm. What is the spring constant of this spring?

a) Less than 8N/m
b) 8N/m
c) More than 8N/m
d) Can't determine from information given

Less extension for same force ⇒ stiffer spring ⇒ higher value of k.

mg = kx in equilibrium when net force = 0.
k = mg/x
Smaller x ⇒ bigger k

Which spring exerted the bigger upwards force on the apple?

a) The weak spring which had a large extension
b) The stiffer spring (smaller extension)
c) They exerted the same upwards force
d) Can’t tell from this information

Which spring exerted the bigger upwards force on the apple?

a) The weak spring which had a large extension
b) The stiffer spring (smaller extension)
c) They exerted the same upwards force
d) Can't tell from this information

In BOTH cases, in equilibrium, the net force = 0

$\Rightarrow mg = kx$

mg is the weight of the apple and the same in both cases

$\Rightarrow$ The upwards force the the spring (kx) is the same in both cases

What is the definition of acceleration?

a) Gradient of a position vs time graph
b) Gradient of a velocity vs time graph
c) Acceleration = change in position/ time taken
d) a and c
e) b and c

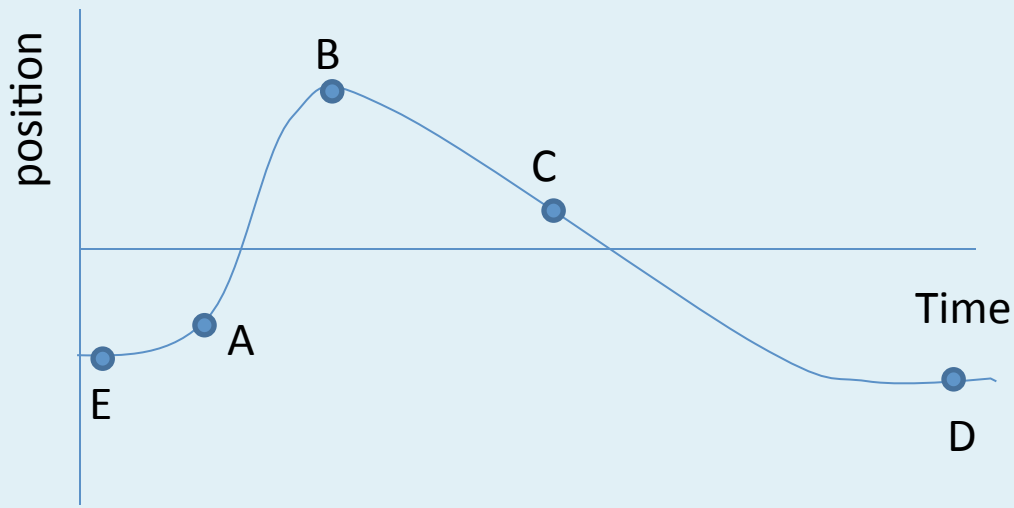
What is the definition of acceleration?

a) Gradient of a position vs time graph
b) Gradient of a velocity vs time graph
c) Acceleration = change in position/ time taken
d) a and c
e) b and c

<u>Acceleration</u> = Gradient of a Velocity vs Time graph

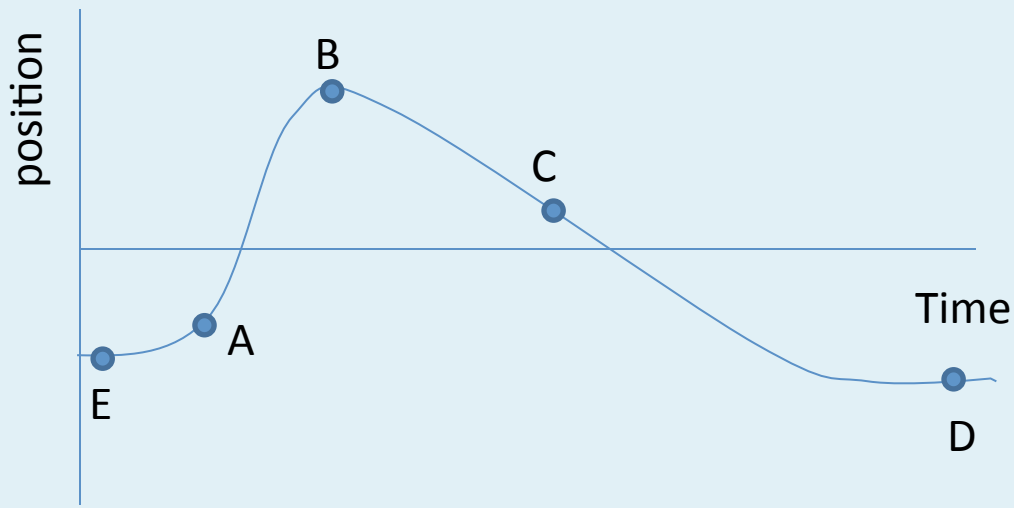
= Change in Velocity/Time taken

$= \underline{\Delta v} / \Delta t$



What is the man's velocity at A

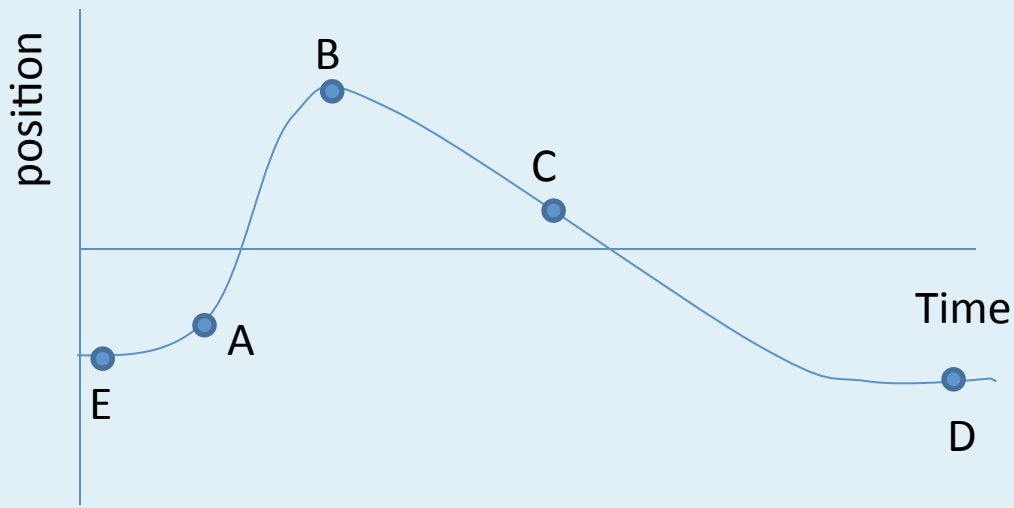
a) Positive
b) Negative
c) Zero
d) Can't be determined



What is the man's velocity at A

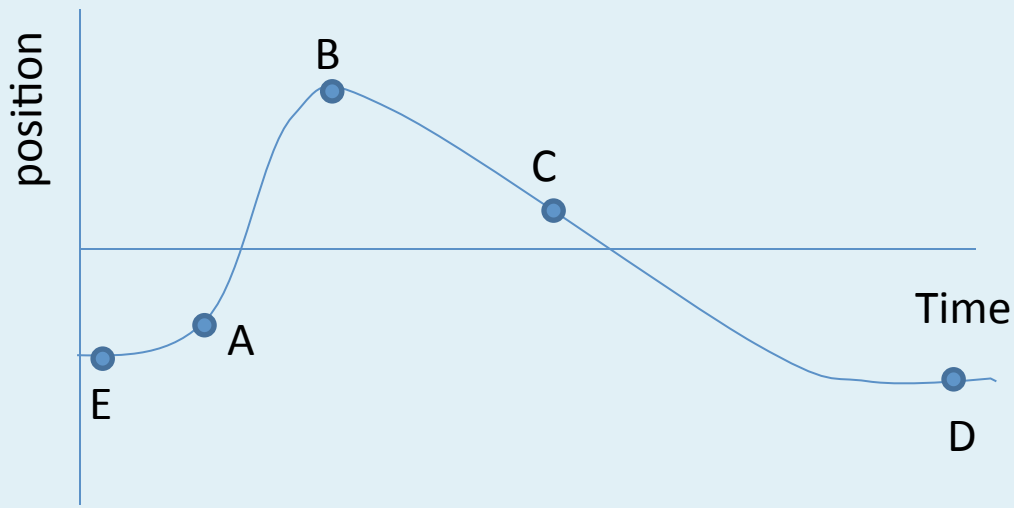
a) Positive
b) Negative
c) Zero
d) Can't be determined

Velocity is the GRADIENT of a position vs time graph



Name all points where the man is stationary

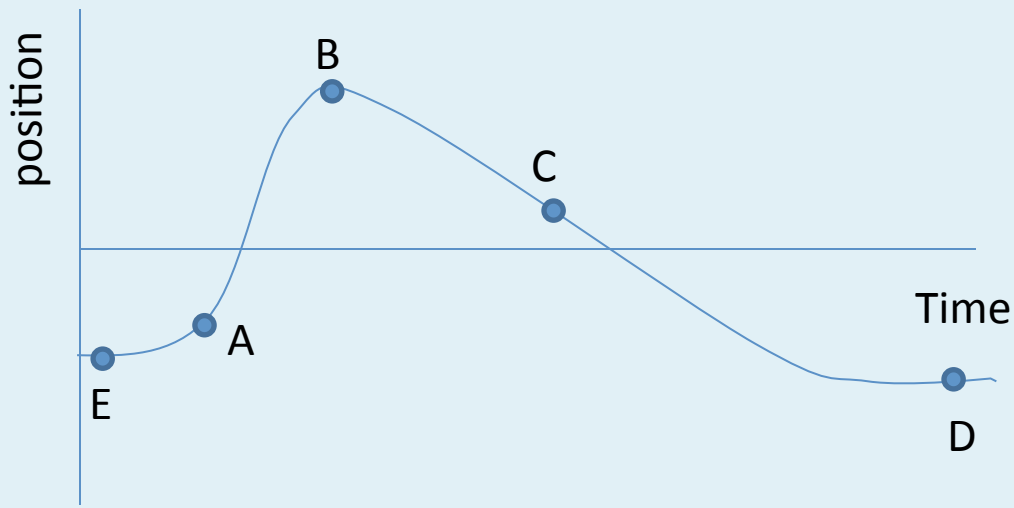
a) E, B and D
b) E and D
c) All points
d) E, C and D
e) B only



Name all points where the man is stationary

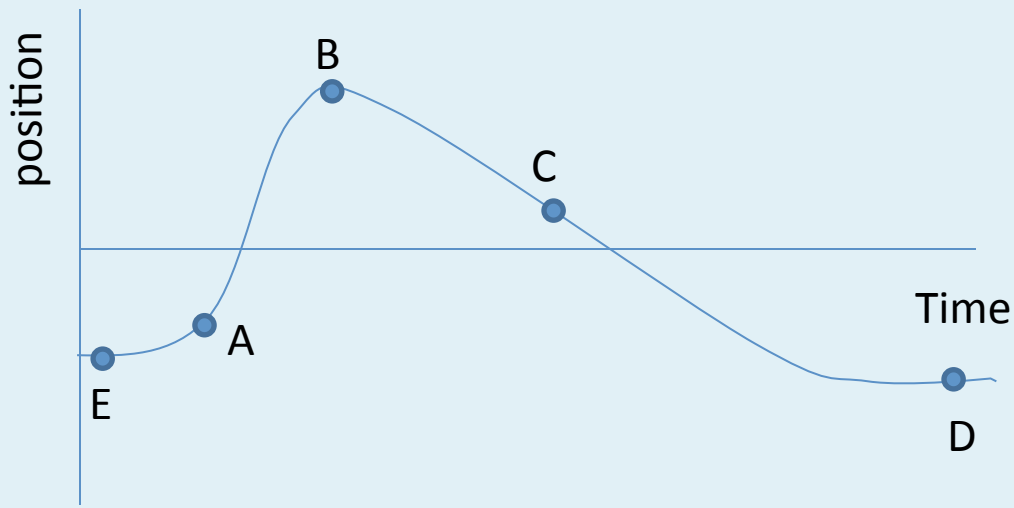
a) E, B and D
b) E and D
c) All points
d) E, C and D
e) B only

Man is stationary when velocity = 0.
Velocity is the gradient of a position vs time graph.
Man is stationary when the graph has zero gradient (horizontal) , even is only instantaneously



Name all the points where the man is accelerating

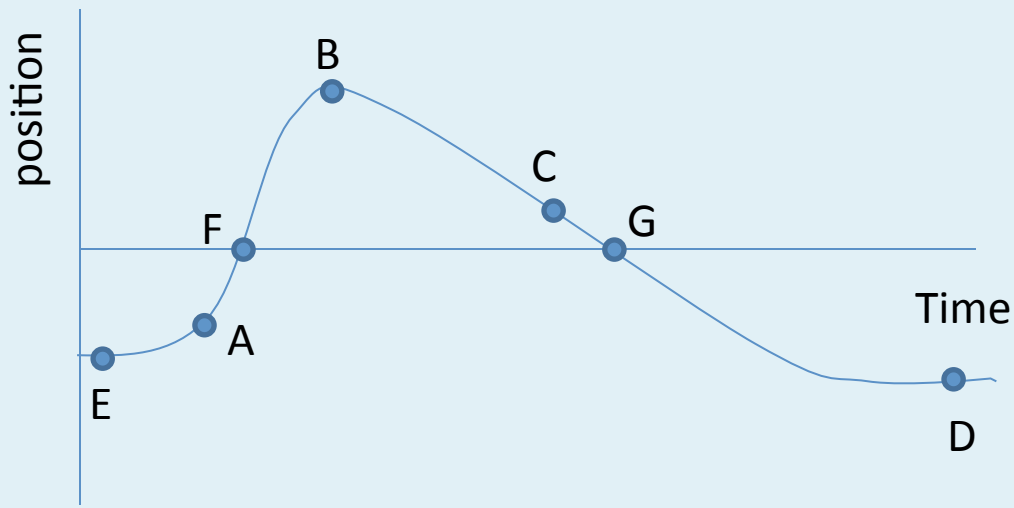
a) A, B and C
b) B only
c) All points
d) A and C
e) A and B



Name all the points where the man is accelerating

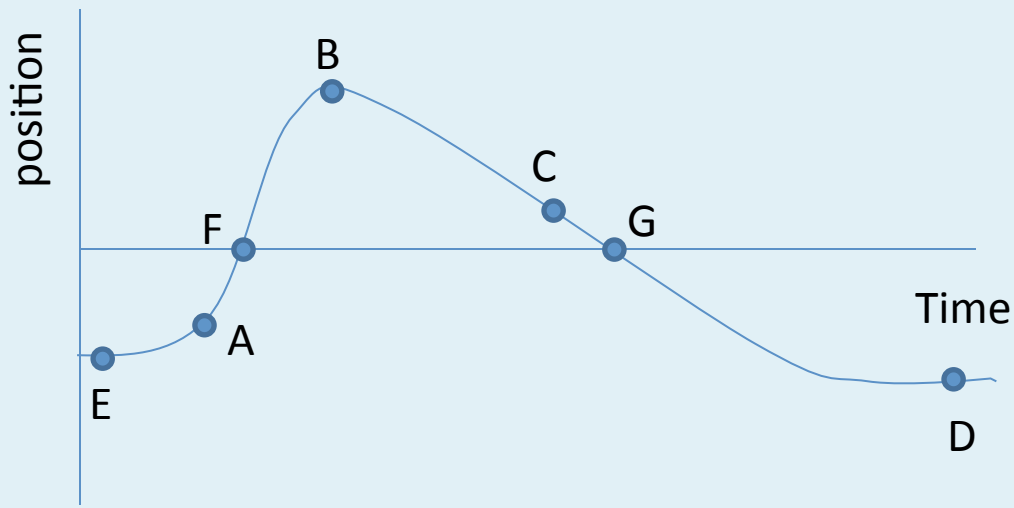
a) A, B and C
b) B only
c) All points
d) A and C
e) A and B

When the man is accelerating his velocity is changing
Velocity is the gradient of a position vs time graph
⇒ So when he is accelerating, the gradient of this graph is changing



What is the man's average velocity between points F and G?

a) Something greater than zero (positive)
b) Something less than zero (Negative)
c) Zero
d) Can't determine from this graph



What is the man's average velocity between points F and G?

a) Something greater than zero (positive)
b) Something less than zero (Negative)
c) Zero
d) Can't determine from this graph

Average velocity = change in position/time taken
At F and G the man is at the SAME position, so the change in position is 0.
⇒ Average velocity is zero