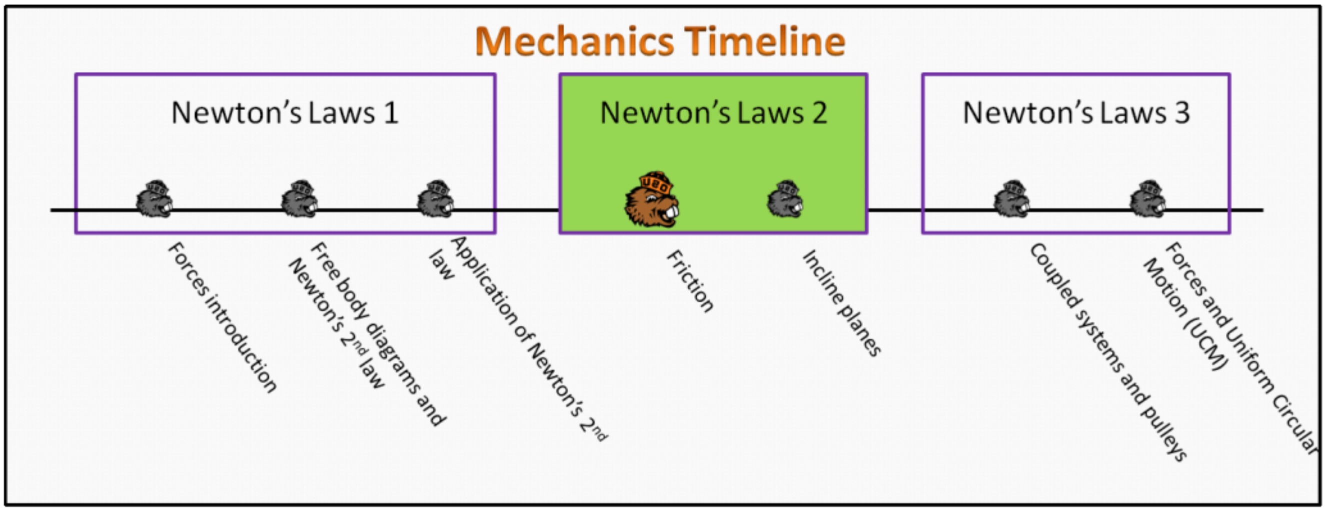
(N2.L1.2-sols) Foundation Stage Solutions

Monday, January 22, 2018   5:44 PM

Newton's Laws 2
Foundation Stage (N2.2)

lecture 1
Friction



Textbook Chapters

- **BoxSand** :: KC videos (Friction)
- **Giancoli** (Physics Principles with Applications 7th) :: 4-8
- **Knight** (College Physics : A strategic approach 3rd) :: 5.5
- **Knight** (Physics for Scientists and Engineers 4th) :: 6.4

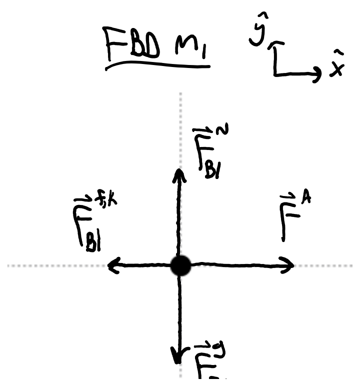
Warm up

N1.2-1:

Description: Given all forces acting on a mass and the mass, find the acceleration of the object.

Learning Objectives: [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

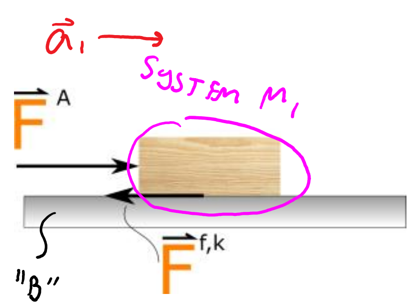
Problem Statement: A 10-kg wooden box is pushed across a stationary horizontal table and the acceleration is measured to be a constant 3 m/s^2 horizontally to the right. The person pushing on the box is applying 50 N of force horizontally to the right. Friction is present in this scenario and acts in the opposite direction that the box slides while on the table. What is the magnitude ofthe frictional force acting on this box? Hint: Draw a FBD and try applying Newton's 2nd law in the horizontal direction first.



$$\Sigma F_x = m_1 a_{1x}$$

$$|\vec{F}^A| - |\vec{F}^{f_k}_{B1}| = m_1 a_{1x}$$

$$|\vec{F}^{f_k}_{B1}| = |\vec{F}^A| - m_1 a_{1x}$$



$\vec{F}_{E1}^{g}$

"B"

$$|\vec{F}_{B1}^{f_k}| = |\vec{F}^{A}| - m_1 a_{1x}$$

$$= 50\,N - (10\,kg)(3\,m/s^2)$$

$$\boxed{|\vec{F}_{B1}^{f_k}| = 20\,N}$$

Selected Learning Objectives

1. Recognize that friction is an interaction between surfaces and therefore depends on both materials.
2. Demonstrate that if two objects are not sliding relative to each other, than the static friction force is as large as it needs to be, up to a maximum value.
3. Demonstrate that if two objects are sliding relative to each other, then the kinetic friction force is constant.
4. Show how the magnitude of the friction force is related to the magnitude of the normal force, via the coefficient of friction; always true for kinetic friction and only true for static friction when it's a maximum.
5. Identify the mechanisms that go into rolling friction and how the magnitude depends on the normal force.
6. Identify a system where rolling friction is present and not negligible.
7. Show that the friction force is parallel to a surface.
8. (UPMF) Demonstrate that the direction of the friction force is opposite the direction of relative motion (or what relative motion would occur without friction) between two surfaces.
9. (UPMF) Demonstrate that if friction is the only force acting in a given direction, then it must be in the same direction as the acceleration component in that direction.
10. Use multiple approaches to make sense of the direction of friction, e.g. connecting the FBD to the direction of the net force and acceleration.
11. Identify other forces related to friction, including air resistance, viscosity, and cohesion.
12. Recognize when friction can safely be neglected.
13. Identify the direction of acceleration and weigh the value of aligning your coordinate system with that direction as opposed to choosing one that minimizes the number of force components.
14. Orient the forces in a FBD in the direction they are applied and not rotated to align with a horizontal or vertical direction.
15. Translate a given angle in the physical representation to all like angles in a FBD, which may require geometry.

Key Terms

- Friction
- Coefficient of kinetic friction
- Coefficient of static friction
- Coefficient of rolling friction
- Kinetic friction
- Static friction
- Maximum static friction
- Rolling friction
- Relative motion

Key Equations

Force
Type of force: kinetic friction
Type of force: normal

$$|\vec{F}_{1\,2}^{f,k}| = \mu_k\, |\vec{F}_{1\,2}^{N}|$$

Object or system 1 on 2
Coefficient of kinetic friction

In words: The magnitude of kinetic friction from 1 on 2 is equal to the coefficient of kinetic friction between objects 1 and 2 times the magnitude of the normal force from 1 on 2.

Force
Type of force: maximum static friction
Type of force: normal

$$|\vec{F}_{1\,2}^{f,s\,max}| = \mu_s\, |\vec{F}_{1\,2}^{N}|$$

Object or system 1 on 2
Coefficient of static friction

In words: The magnitude of maximum static friction from 1 on 2 is equal to the coefficient of static friction between objects 1 and 2 times the magnitude of the normal force from 1 on 2.

Force
Type of force: static friction
Type of force: normal

$$|\vec{F}_{1\,2}^{f,s}| < \mu_s\, |\vec{F}_{1\,2}^{N}|$$

Object or system 1 on 2
Coefficient of static friction

In words: The magnitude of static friction from 1 on 2 is less than the coefficient of static friction between objects 1 and 2 times the magnitude of the normal force from 1 on 2.

Key Concepts

- Friction is always parallel to the two surfaces in contact with each other.
- Friction always points in the opposite direction of relative motion (or what relative motion would occur if friction were not present) between two surfaces.
- The coefficient of static, kinetic, and rolling friction are all dependent on the properties of the two materials in contact.
- Coefficients of friction can be larger than 1.
- Kinetic friction is a constant value when two objects are sliding relative to each other. The magnitude of this kinetic friction is equal to the coefficient of kinetic friction between the two surfaces times the magnitude of the normal force between the two surfaces.
- Static friction is as large as it needs to be, up to a maximum value, before the two surfaces begin to slide relative to each other.
- All objects with wheels have friction acting on the wheels when the wheels are freely rolling; this friction is called rolling friction. Rolling friction arises due to a few different complicated mechanisms (e.g. deformation of the wheels on contact, bearings, etc…). Rolling friction is different than the static friction between wheels and the ground when a car is accelerating. Static friction is present between the wheels and the ground because there is a mechanism trying to rotate the wheels (driven wheels) about their axis.

Act I: Kinetic friction

Questions

N1.2-2:

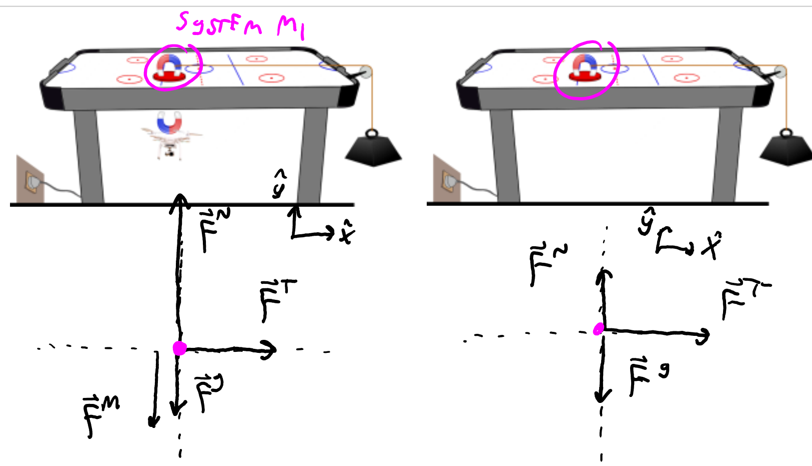
Description: Conceptual questions exploring the features of kinetic friction (3 minutes + 2 minutes + 2 minutes)

Learning Objectives: [4, 12]

Problem Statement: Consider two identical systems as shown below. The only difference is a drone carrying a magnet under the left system which keeps the magnets aligned at all times. The magnets are attracting each other in the left system.

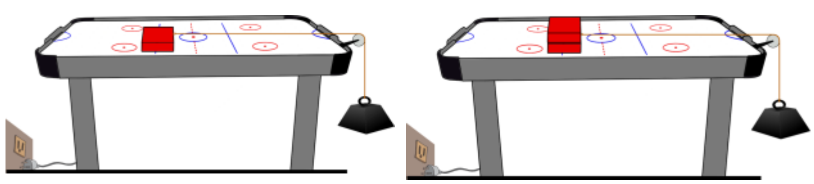
(a) Assuming negligible friction, which air hockey puck will have a greater acceleration?

(1) Left
(2) Right
(3) Equal accelerations.



MAGNET ONLY AFFECTS VERTICAL DIRECTION FORCES. W/OUT FRICTION THIS DOESN'T CHANGE a_x

(b) The air hockey table is now unplugged and friction is not negligible. If the normal force between the table and the puck doubles, what happens to the kinetic friction between the table and the puck?



(1) Stays the same.
(2) Doubles.
(3) Halves.

$|\vec{F}^{F,k}| = \mu_k |\vec{F}^N|$

IF $F^N \uparrow 2$

(1) Stays the same.
(2) Doubles.
(3) Halves.

$|\vec{F}^{F,k}| = \mu_k |\vec{F}^{N}|$

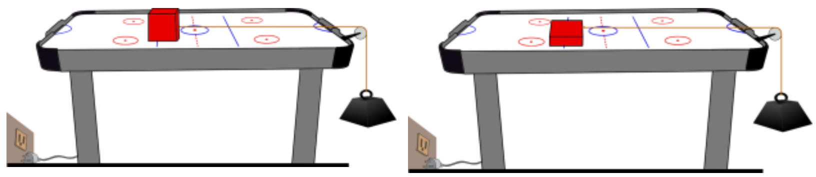
μ_k IS CONSTANT HERE

SO... $|\vec{F}^{f,k}| \propto |\vec{F}^{N}|$

IF $F^N \uparrow 2$

THEN $F^{FK} \uparrow 2$

(c) What happens to the kinetic friction if the contact area of the puck and the table doubles?



(1) Stays the same.
(2) Doubles.
(3) Halves.

OUR MODEL ... INDEPENDENT OF CONTACT AREA.

N1.2-3:

Description: Conceptual question about the nature of frictional forces. (3 minutes)

Learning Objectives: [1]

Problem Statement: A wooden block slides to rest on a metal table. The coefficient of kinetic friction depends *only* on which of the following?

μ_k

F (1) The surface properties of the wooden block.
T (2) The surface properties of both the wooden block and the table.
F (3) The normal force acting on the object.
F (4) The acceleration of the block.
F (5) The velocity of the block.

N1.2-4:

Description: Given mass, μ_k, and initial speed, determine the time it takes a block to slide to rest on a horiztonal table. (1 minute + 2 minutes + 5 minutes)

Learning Objectives: [3, 4, 7]

minutes + 5 minutes)

Learning Objectives: [3, 4, 7]

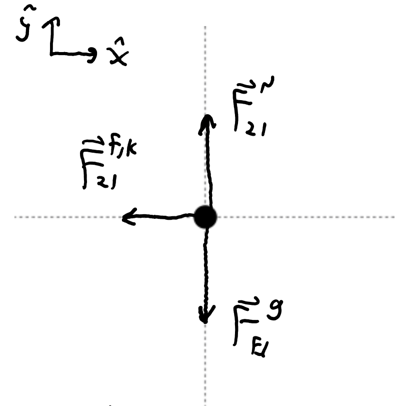
Problem Statement: A 2.00 kg wooden block, sliding to the right, comes to rest on a stationary metal table. The coefficient of kinetic friction between the block and the table is 0.25 The blocks initial speed is 4.00 m/s. We wish to determine how much time it takes the block to side to rest.

(a) What is the direction of the friction acting on the block?

(1) Left
(2) Right
(3) Impossible to determine

BLOCK SLIDING RIGHT RELATIVE TO TABLE. SO $\vec{F}^{fk} \leftarrow$

(b) Draw a FBD with the block as your system



(c) How much time it takes the block to side to rest?

FORCE ANALYSIS

$$\Sigma F_x = m_1 a_{1x} \qquad \Sigma F_y = m_1 \cancel{a_{1y}}^{\,0}$$

$$-|\vec{F}_{21}^{fk}| = m_1 a_{1x} \qquad |\vec{F}_{21}^{N}| - |\vec{F}_{E1}^{g}| = 0$$

$$-\mu_k |\vec{F}_{21}^{N}| = m_1 a_{1x} \qquad |\vec{F}_{21}^{N}| - m_1 g = 0$$

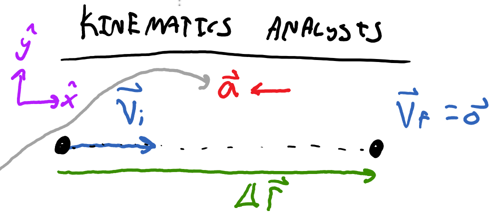
2 EQNS
2 UNKNOWNS

$$|\vec{F}_{21}^{N}| = m_1 g$$

$$-\mu_k \cancel{m_1} g = \cancel{m_1} a_x$$

$$a_x = -\mu_k g \approx -2.45 \text{ m/s}^2$$

KINEMATICS ANALYSIS



X

k	uk
$V_{ix} = 4$ m/s	Δx
$V_{fx} = 0$	Δt
$a_x = -\mu_k g$	

$$\Delta x = V_{ix}\Delta t + \tfrac{1}{2} a_x \Delta t^2$$

$$V_{fx} = V_{ix} + a_x \Delta t$$

$$\cancel{V_{fx}}^{\,0} = V_{ix} + a_x \Delta t$$

$$0 = V_{ix} - \mu_k g \Delta t$$

$$\Delta t = \frac{V_{ix}}{\mu_k g} = \frac{4 \text{ m/s}}{(0.25)(9.8) \text{ m/s}^2} = \boxed{1.63 \text{ sec}}$$

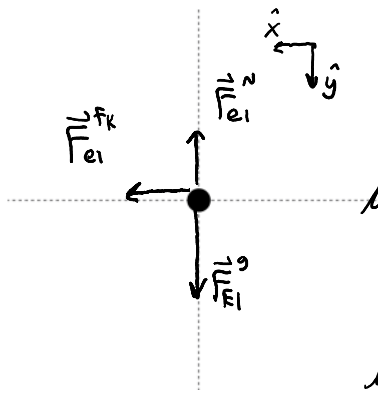
N1.2-5:

Description: Sketch a scaled FBD for a box that is in a non-inertial reference frame; the FBD is to be drawn from an inertial reference frame. (2 minutes + 4 minutes)

Learning Objectives: [3, 4, 7]

Problem Statement: A box is sliding to the right on the floor of an elevator that is moving upwards and slowing down.

(a) Sketch a FBD of the box during the time is slides to rest being careful to scale the vectors relative to each other.



$\Sigma F_x = m_1 a_{1x}$ $\quad\quad$ $\Sigma F_y = m_1 a_{1y}$

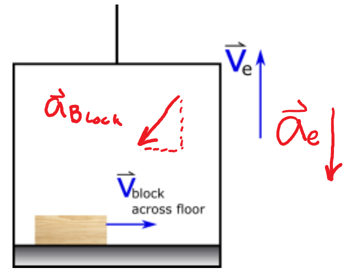
$|\vec{F}^{fk}_{e1}| = m_1 a_{1x}$ $\quad\quad$ $-|\vec{F}^{N}_{e1}| + |\vec{F}^{g}_{E1}| = m_1 a_{1y}$

$\mu_k |\vec{F}^{N}_{e1}| = m_1 a_{1x}$ $\quad\quad$ $-|\vec{F}^{N}_{e1}| + m_1 g = m_1 a_{1y}$

$|\vec{F}^{N}_{e1}| = m_1 g - m_1 a_{1y}$

$$\mu_k(\cancel{m_1} g - \cancel{m_1} a_{1y}) = \cancel{m_1} a_{1x}$$

$$\mu_k(g - a_{1y}) = a_{1x}$$



(b) How does the time it takes the box to come to rest compare to if the elevator was in equilibrium?

(1) more time
(2) less time
(3) same time

IF ELEVATOR IS IN E.Q. $\quad \Sigma F_y = 0$

$$|\vec{F}^{N}_{e1}| = |\vec{F}^{g}_{E1}|$$

FROM PART (a) ... IF $\vec{a} \downarrow$ $\quad |\vec{F}^{N}_{e1}| < |\vec{F}^{g}_{E1}|$

LOOK @ ΣF_x FROM (a)

$$\mu_k |\vec{F}^{N}_{e1}| = m_1 a_{1x}$$

$$a_x \propto |\vec{F}^{N}_{e1}|$$

SO IF $|\vec{F}^{N}_{e1}| \downarrow$ THEN $a_{1x} \downarrow$

THUS $\Delta t \uparrow$

So if $|\vec{F}_a| \downarrow$ THEN $a_{1x} \downarrow$

$\boxed{\text{THUS } \Delta t \uparrow}$

Act II: Static friction

N1.2-6:

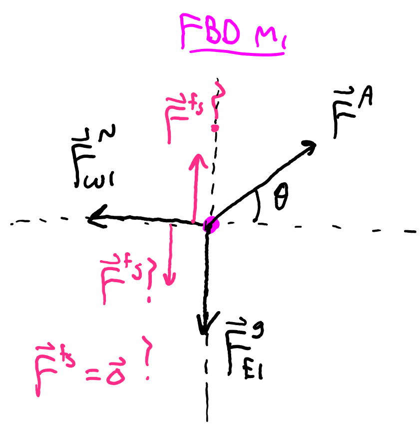
Description: Given that an object is at rest and a picture, determine direction of static friction. (4 minutes)

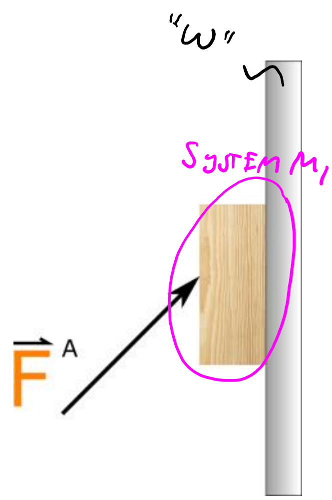
Learning Objectives: [7, 8]

Problem Statement: What is the direction of friction on the block if the box is not moving?

(1) Towards the right
(2) Downwards
(3) Upwards
(4) Not enough information

DEPENDS ON $|\vec{F}^A|$ AND θ





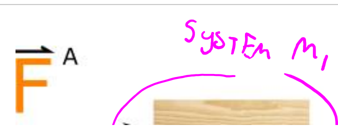
N1.2-7:

Description: Given mass, μ_s, μ_k, and magnitude of applied force, determine the acceleration of the box on a horizontal surface. (3 minutes + 3 minutes)

Learning Objectives: [2, 7, 8]

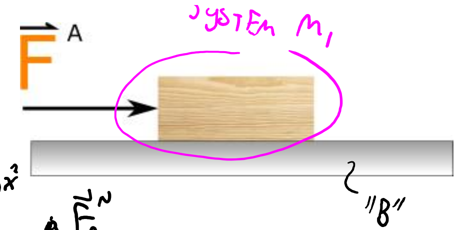
Problem Statement: A 0.250 kg block is at rest on top of a horizontal table. The coefficient of static friction between the table and block is 0.50, and the coefficient of kinetic friction between the two is 0.10. A person then applies a 1.00 N force horizontally to the right.

(a) What is the magnitude of the friction force between the block and table?



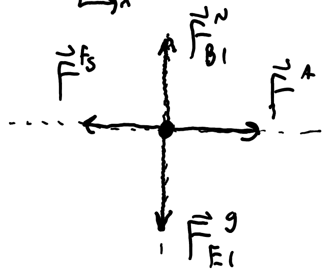
(1) 0 N

(a) What is the magnitude of the friction force between the block and table?



(1) 0 N
(2) 0.245 N
(3) 0.980 N
(4) 1.00 N
(5) 1.23 N
(6) 2.45 N

LOOK @ ΣF_x ... IS $|\vec{F}^A|$ ENOUGH TO OVERCOME $|\vec{F}^{fs\,max}|$?



$\Sigma F_y = \cancel{m a_{1y}}^{0}$

$$|\vec{F}^{fs\,max}| = \mu_s |\vec{F}^N_{B1}|$$

$$|\vec{F}^N_{B1}| = m_1 g$$

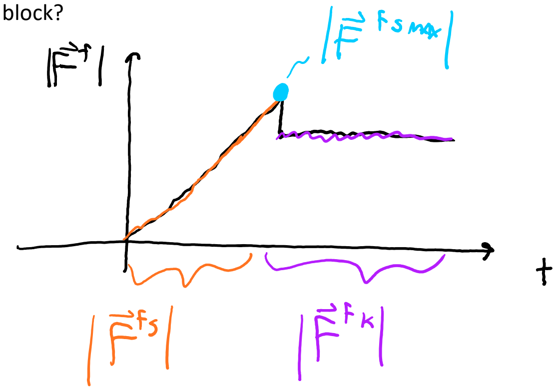
$$|\vec{F}^{fs\,max}| = \mu_s m_1 g$$

$$|\vec{F}^{fs\,max}| = (0.5)(.25\ kg)(9.8\ m/s^2) \approx 1.23\ N$$

so $|\vec{F}^A| < |\vec{F}^{fs\,max}|$

(b) What is the acceleration of the block?

(1) < 0 , 0 > m/s^2
(2) < 0.980 , 0 > m/s^2
(3) < 3.92 , 0 > m/s^2
(4) < 4.00 , 0> m/s^2
(5) < 4.92 , 0 > m/s^2
(6) < 9.80 , 0 > m/s^2



N1.2-8:

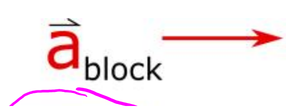
Description: Given information about acceleration of object, determine direction of friction and velocity of object. (4 minutes + 4 minutes + 2 minutes + 3 minutes + 5 minutes)

Learning Objectives: [2, 7, 8. 9, 10]

Problem Statement: The block is accelerating to the right on top of a hand as shown below.

(a) What is the direction of the friction on the block from the hand?

FBD m_1 $\quad \vec{a} \longrightarrow$

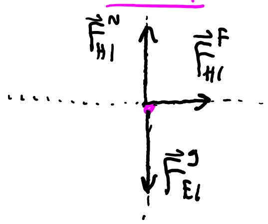


(1) Towards the right

(a) What is the direction of the friction on the block from the hand?

(1) Towards the right
(2) Towards the left
(3) Not enough information

FBD m_1

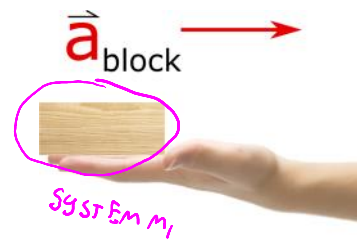


$\vec{a} \longrightarrow$

$\Sigma \vec{F} = m\vec{a}$

so

$\Sigma \vec{F} \longrightarrow$



DIRECTION?

METHOD 1

CHECK IF FRICTION IS THE ONLY FORCE ALONG THE AXIS OF ACCELERATION.
IF IT'S THE ONLY FORCE, THEN IT MUST POINT IN SAME DIRECTION OF $\vec{a}$

METHOD 2

IMAGINE IF NO FRICTION WERE PRESENT... WHAT DIRECTION WOULD OBJECT SLIDE RELATIVE TO SURFACE? FRICTION IS THEN IN THE OPPOSITE DIRECTION

(b) What is the direction of the velocity of the block?

(1) Towards the right
(2) Towards the left
(3) Momentarily stationary
(4) Not enough information

SPEEDING UP

$\vec{V} \longrightarrow$

$\vec{a} \longrightarrow$

$\vec{V} \longleftarrow$

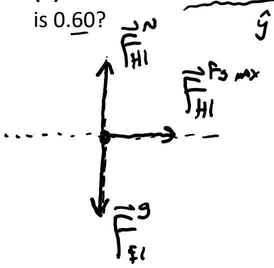
$\vec{a} \longrightarrow$

SLOWING DOWN

(c) Is the friction from the hand on the block static or kinetic friction?

(1) Static
(2) Kinetic
(3) Not enough information.

(d) What is the maximum acceleration the 0.50 kg block can undergo if the coefficient of static friction between the hand and the block is 0.60?



$$\Sigma F_x = m_1 a_{1x}$$

$$\Sigma F_y = m_1 \cancel{a_{1y}}^{\,0}$$

$$|\vec{F}^{Fs\,max}_{H1}| = m_1 a_{1x}$$

$$|\vec{F}^{N}_{H1}| = m_1 g$$

$$\mu_s |\vec{F}^{N}_{H1}| = m_1 a_{1x}$$

$$\mu_s \cancel{m_1} g = \cancel{m_1} a_{1x}$$

$$\boxed{a_{1x} = \mu_s g}$$

$$\boxed{a_{1x} = \mu_s g}$$

Conceptual questions for discussion

1. While listening to two physics students talk about friction, you hear one student say that the coefficient of rubber is about 0.70. Do you agree with this statement? If so why? If not, provide an explanation as to what you would change to make the statement correct.
2. What are the SI units for coefficient of friction?
3. A box is initially at rest on top of the bed of a truck as shown below. The truck then begins to accelerate to the right such that the maximum static friction is no longer able to keep the box stationary with respect to the truck, thus the box begins to slide on the bed of the truck. There are two observers, one who stands stationary on the truck bed, and another on the side of the street. Describe the motion of the box that each observer sees.

Hints

N1.2-1: No hints.

N1.2-2: Draw a FBD for both cases in part a.

N1.2-3: No hints.

N1.2-4: How does a force analysis connect to kinematics?

N1.2-5: Determine the direction of acceleration; does your FBD show a net force pointing in the same direction?

N1.2-6: No hints.

N1.2-7: Remember that static friction will vary in magnitude until it reaches its maximum possible vale right before the object begins to slide.

N1.2-8: Good luck :)