(N1) FBDs and Newton's 2nd Law

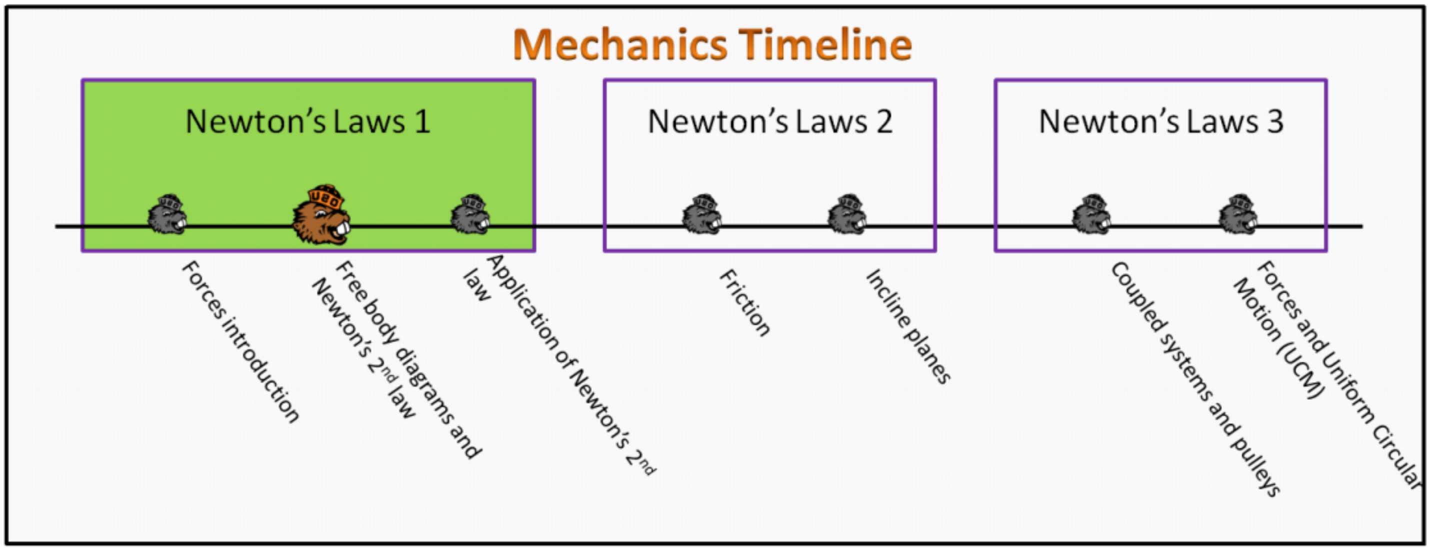
Monday, January 22, 2018 5:44 PM

Newton's Laws 1

Foundation Stage (N1.2)

lecture 2

Free Body Diagrams and Newton's 2nd law



Textbook Chapters

- **BoxSand** :: KC videos (Newton's Second Law)
- **Giancoli** (Physics Principles with Applications 7th) :: 4-4 ; 4-6 ; 4-7
- **Knight** (College Physics : A strategic approach 3rd) :: 4.5 ; 4.6 ; 5.1 ; 5.2 ; 5.3
- **Knight** (Physics for Scientists and Engineers 4th) :: 5.5 ; 5.7 ; 6.1 ; 6.2 ; 6.3

Warm up

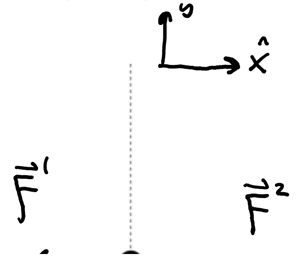
N1.2-1:

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 100000-kg spaceship has two forces acting on it: $\vec{\mathbf{F}}^1 = < -5000\,, 0 > N$ and $\vec{\mathbf{F}}^2 = < 25000\,, 0 > N$. Assume a standard coordinate system.

(a) Sketch a FBD for this spaceship.

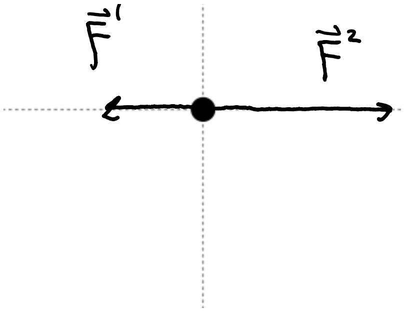


(b) What is the acceleration of this spaceship

$$\Sigma F_x = m a_x$$

$$|\vec{F}^2| - |\vec{F}^1| = m a_x$$

$$25000\ N - 5000\ N = 100000\ kg\ a_x$$



$$25000\ N - 5000\ N = 100000\ kg\ a_x$$

$$a_x = 5\ m/s^2$$

$$\boxed{\vec{a} = \langle 5, 0 \rangle\ m/s^2}$$

Selected Learning Objectives

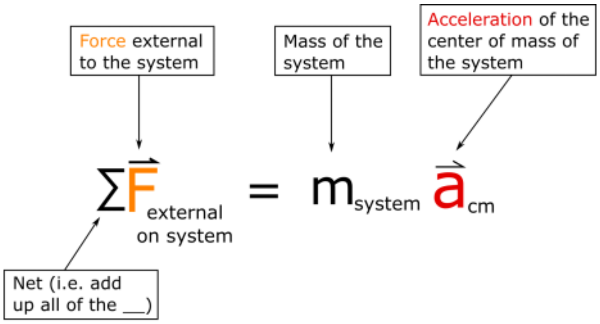
1. Demonstrate the fact that a force is inherently an interaction between two objects or two systems.
2. Explain Newton's 1st law as it relates to inertia.
3. Explain Newton's 1st law and how it relates to the 2nd law.
4. Define static and dynamic equilibrium.
5. Explain Newton's 2nd Law.
6. Explain Newton's 3rd Law force pairs.
7. Define the point particle model.
8. Define a system(s) boundary and adhere their analysis to that boundary(s).
9. Identify the type of forces interacting with your system and the direction they are applied.
10. Differentiate between contact and non-contact forces.
11. Demonstrate that the normal force is always perpendicular to the surface.
12. Draw a free-body-diagram (FBD) for the system(s).
13. Demonstrate the ability to draw a *properly scaled* FBD.
14. (UPMF) Draw the coordinate system that reduces the complexity of the vector analysis next to the FBD.
15. Apply geometry to determine appropriate angles for the given coordinate system.
16. Find the components of a force in the chosen coordinate system.
17. Differentiate between *A* force and a *NET* force.
18. Apply Newton's 2nd law in the mathematical representation.
19. Differentiate between static and dynamic equilibrium.
20. Differentiate between weight and apparent weight.
21. Synthesize a force and kinematics analysis via the acceleration.
22. Demonstrate that the net force points in the same direction as the acceleration.
23. Demonstrate the fact that the net force can be in the opposite direction of the motion.

Key Terms

- Newton's 2nd law
- Equilibrium
- Tension
- Applied force
- Push force
- Pull force
- Critical quantity (e.g. critical angle)

Key Equations

Newton's 2nd law



In words: The net force external to the system is equal to the mass of the system multiplied by the acceleration of the center of mass of the system.

Key Concepts

- Net force points in the same direction as acceleration.
- If a system is in equilibrium, then a scaled FBD should show that all of the external forces add to zero.
- Applied force, push force, and pull force are just generic place holders for real forces. They are often used when knowledge of the type of interaction does not provide any significant insight to the force analysis.
- When a quantity reaches a certain value where an interesting observation is noticed, the quantity's value is often referred to as a critical value.
- Force analysis and kinematics are related to each other via acceleration.

Act I: Application of Newton's 2nd law

Questions

N1.2-2:

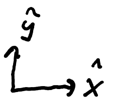
Description: Sketch a scaled FBD. (2 minutes)

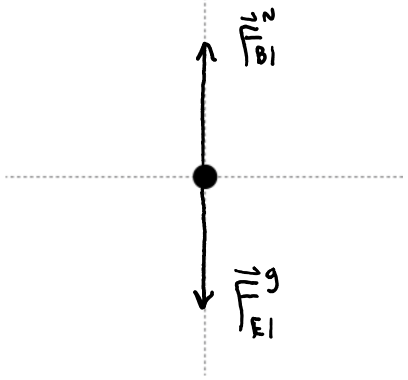
Learning Objectives: [9, 12, 13, 22]

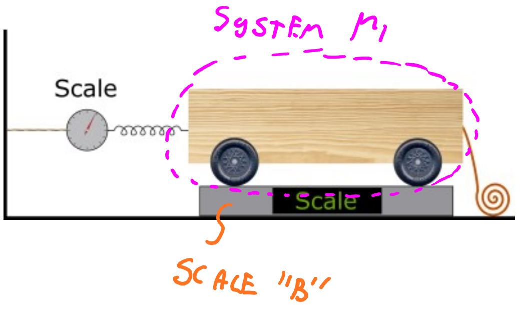
Problem Statement: A box with wheels is on top of a horizontal scale as shown below. Attached to one side is a horizontal rope with a spring scale to measure force (assume the scale and the ropes are mass-less). On the other side of the box is a rope that has no force being applied to it. Assume equilibrium.

$\sum \vec{F} = \vec{0}$

Sketch a scaled FBD of the box.







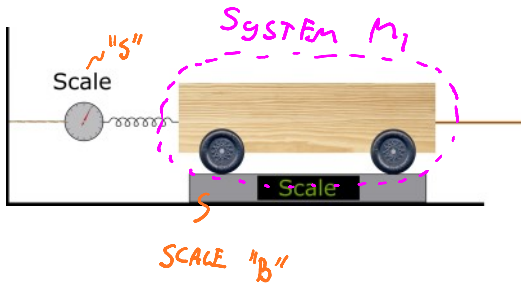
N1.2-3:

Description: Sketch a scaled FBD and apply Newton's 2nd law in the mathematical representation. (3 minutes + 2.5 minutes + 2.5 minutes + 1 minute + 2 minutes)

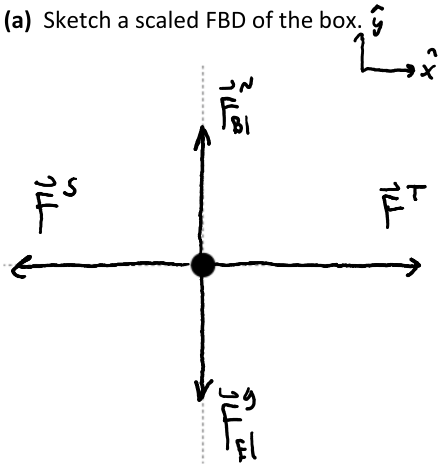
Learning Objectives: [9, 12, 13, 18, 22]

Problem Statement: A 10-kg-box with wheels is on top of a horizontal scale. Attached to one side is a horizontal rope with a spring scale to measure force (assume the scale and the ropes are mass-less). One the other side of the box is a rope that now has a horizontal force equal to 150 N pulling on it. Assume in equilibrium.

$\Sigma \vec{F} = \vec{0}$



(a) Sketch a scaled FBD of the box.



(b) What is the reading on the bottom scale?

$$\Sigma F_y = m_1 \cancel{a_y}^{0}$$

$$|\vec{F}^N_{B1}| - |\vec{F}^g_{E1}| = 0$$

$$|\vec{F}^N_{B1}| - mg = 0$$

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

$$\approx \boxed{100\ N}$$

(c) What is the reading on the spring scale?

$$\Sigma F_x = m_1 \cancel{a_x}^{0}$$

$$|\vec{F}^T| - |\vec{F}^S| = 0$$

$$|\vec{F}^S| = |\vec{F}^T|$$

$$\boxed{|\vec{F}^S| = 150\ N}$$

(d) The force from the spring scale is equal in magnitude and opposite the direction of the tension from the rope. Are these two forces Newton's 3rd law force pairs?

(1) Yes
[✓ (2) No]

A FORCE IS AN INTERACTION BETWEEN 2 OBJECTS

SO FORCE PAIRES ARE THE 2 FORCES DESCRIBING AN INTERACTION.... SO MOST BE SAME TYPE OF FORCE .... ALSO WILL NEVER SHOW UP ON SAME FBD

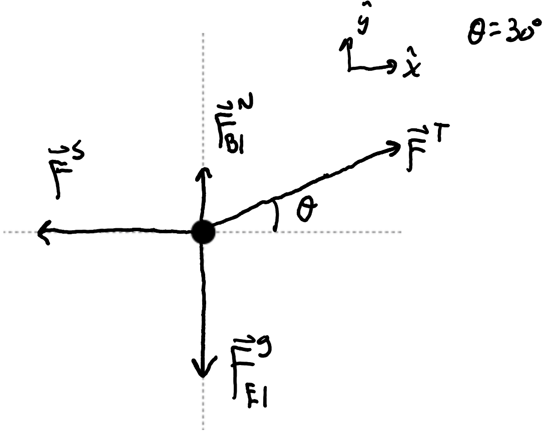
N1.2-4:

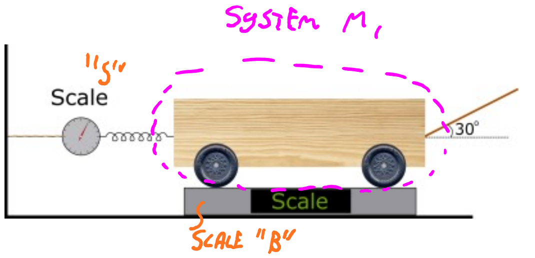
Description: Sketch a scaled FBD and apply Newton's 2nd law in the mathematical representation. (2 minutes + 3 minutes + 2 minutes + 8 minutes)

Learning Objectives: [9, 12, 13, 16, 18, 22]

Problem Statement: A 10-kg-box with wheels is on top of a horizontal scale. Attached to one side is a horizontal rope with a spring scale to measure force (assume the scale and the ropes are mass-less). One the other side of the box is a rope that now has a force equal to 150 N pulling on it in a direction of 30 degrees up from the horizontal.

(a) Sketch a scaled FBD of the box.





(b) The normal force is ___________ mg.

(1) greater than
[✓ (2) less than]
(3) equal to

(c) Which of the following mathematical representations is a correct application of Newton's 2nd law applied to the horizontal direction of the box?

(1) $|\vec{F}^T|\cos(\theta) + |\vec{F}^s| = m_1 a_{1x}$

X (2) $|\vec{F}^T|\sin(\theta) + |\vec{F}^s| = m_1 a_{1x}$

[✓ (3) $|\vec{F}^T|\cos(\theta) - |\vec{F}^s| = m_1 a_{1x}$]

X (4) $|\vec{F}^T|\sin(\theta) - |\vec{F}^s| = m_1 a_{1x}$

(d) Which of the following mathematical representations is a correct application of Newton's 2nd law applied to the vertical direction of the box?

X (1) $|\vec{F}^T|\cos(\theta) + |\vec{F}^N| + |\vec{F}^g_{E1}| = m_1 a_{1y}$

(2) $|\vec{F}^T|\sin(\theta) + |\vec{F}^N| + |\vec{F}^g_{E1}| = m_1 a_{1y}$

X (3) $|\vec{F}^T|\cos(\theta) + |\vec{F}^N| - |\vec{F}^g_{E1}| = m_1 a_{1y}$

[✓ (4) $|\vec{F}^T|\sin(\theta) + |\vec{F}^N| - |\vec{F}^g_{E1}| = m_1 a_{1y}$]

(e) What is the reading on the spring scale?

$$|\vec{F}^T|\cos\theta - |\vec{F}^S| = m_1 \cancel{a_{1x}}^{0}$$

$$|\vec{F}^S| = |\vec{F}^T|\cos\theta$$

$$= 150N\cos(30°)$$

$$\boxed{|\vec{F}^S| \approx 130N}$$

(f) What is the reading on the bottom scale?

$$|\vec{F}^T|\sin\theta + |\vec{F}^N_{B1}| - |\vec{F}^g_{E1}| = m_1 \cancel{a_{1y}}^{0}$$

$$|\vec{F}^T|\sin\theta + |\vec{F}^N_{B1}| - m_1 g = 0$$

$$|\vec{F}^N_{B1}| = m_1 g - |\vec{F}^T|\sin\theta$$

$$= (10kg)(9.8m/s^2) - 150N\sin(30°)$$

$$\boxed{|\vec{F}^N_{B1}| \approx 23N}$$

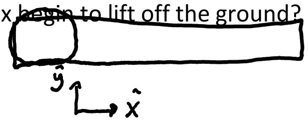
N1.2-5:

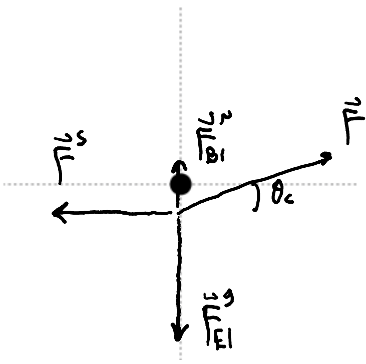
Description: Sketch a scaled FBD and apply Newton's 2nd law in the mathematical representation. (7 minutes)

Learning Objectives: [9, 12, 13, 16, 18, 22]

Problem Statement: A 10-kg-box with wheels is on top of a horizontal scale. Attached to one side is a horizontal rope with a spring scale to measure force (assume the scale and the ropes are mass-less). One the other side of the box is a rope that now has a force equal to 150 N pulling on it in a direction up from the horizontal.

What angle, in degrees, will the box begin to lift off the ground?





$$\Sigma F_x = m_1 \cancel{a_{1x}}^{0}$$

$$\overset{\checkmark}{|\vec{F}^T|}\cos\overset{?}{\theta_c} - \overset{?}{|\vec{F}^s|} = 0$$

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

$$|\vec{F}^T|\sin\theta_c + \cancel{|\vec{F}^N_{B1}|}^{0} - |\vec{F}^g_{E1}| = 0$$

$$\overset{\checkmark}{|\vec{F}^T|}\sin\overset{?}{\theta_c} - \overset{\checkmark}{m_1}\overset{\checkmark}{g} = 0 \;//$$

$$\sin\theta_c = \frac{m_1 g}{|\vec{F}^T|}$$

$$\theta_c = \sin^{-1}\left(\frac{m_1 g}{|\vec{F}^T|}\right) \approx \boxed{40.8^\circ}$$

N1.2-6:

Description: Sketch a scaled FBD and apply Newton's 2nd law in the mathematical representation. (2 minutes + 2 minutes + 4 minutes + 4 minutes)

Learning Objectives: [9, 12, 13, 18, 21, 22]

Problem Statement: Consider a box full of 500, 12.4-kg-gold-bars on a frictionless horizontal table. Janik the yak applies a horizontal force on the box by pushing it with 7000 N of force.

(a) Which of the following are the applied force?

(b) Draw a FBD representing the forces acting on the box full of gold. Be sure to clearly label each force vector so that there is no confusion as to all symbols used

(1) Normal.

? (2) Tension.

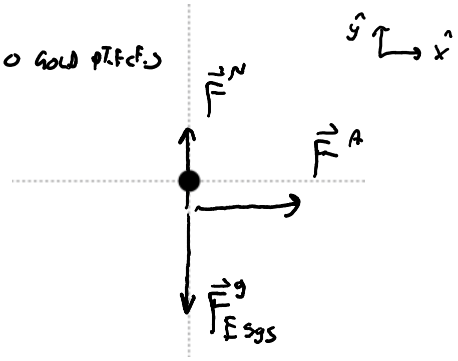
? (3) Push.

? (4) Pull.

? (5) Could be any of these.

O

System = Box w/ 500 Gold pieces



(c) Find the acceleration of the box.

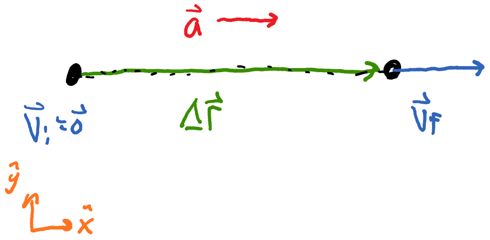
$$\Sigma F_x = m_{sys}\, a_{sys\,x}$$

$N =$ # of Gold BARS

$$|\vec{F}^A| = N\, m_{gold\,bar}\, a_x$$

$$a_x = \frac{|\vec{F}^A|}{N\, M_{gold\,bar}} = \frac{7000\text{ N}}{500\,(12.4\text{ kg})} \approx 1.13$$

(d) Assuming the box started at rest, how far did it travel in the first 2 seconds?



K	UK
$V_{ix} = 0$	Δx
$a_x = 1.13\text{ m/s}^2$	V_{fx}
$\Delta t = 2\text{ s}$	

$$\overset{?}{\Delta x} = \overset{\checkmark}{\cancel{V_{ix}}}^{\,0}\,\overset{\checkmark}{\Delta t} + \tfrac{1}{2}\overset{\checkmark}{a_x}\,\Delta t^2$$

$$\Delta x = \tfrac{1}{2}(1.13)(2)^2$$

$$\boxed{\Delta x \approx 2.26\text{ m}}$$

Conceptual questions for discussion

1. The gravitational force from the earth on a whole gold bar of mass 12.4 kg is larger than the gravitational force from the earth on half of a gold bar with mass 6.2 kg. Ignoring air resistance, use Newton's laws of motion to explain why both gold bars fall at the same rate during projectile motion and free fall.
2. Is it possible for an object to be in static equilibrium with only one force acting on it? If so, provide an example, if not, explain why.
3. Provide examples for an object whose velocity is:
   i. in the same direction as the net force acting on it.
   ii. in the opposite direction as the net force acting on it.
   iii. perpendicular to the net force acting on it.

Hints

N1.2-1: What is Newton's 2nd law?

N1.2-2: Is the box accelerating?

N1.2-3: Is the box accelerating? Also, what is Newton's 2nd law?

N1.2-4: Is the box accelerating? Also, what is Newton's 2nd law?

N1.2-5: The interesting observation here is that the box will just begin to lift off the ground. What happens to the normal force when this is observed?

N1.2-6: No hints.