PHYS 1443 – Section 004
Lecture #9

Thursday, Sept. 18, 2014
Dr. Jaehoon Yu

- Newton's Laws of Motion
  - third law of motion
  - Categories of Forces
  - Gravitational Force and Weight

Today's homework is homework #5, due 11pm, Tuesday, Sept. 23!!

Announcements

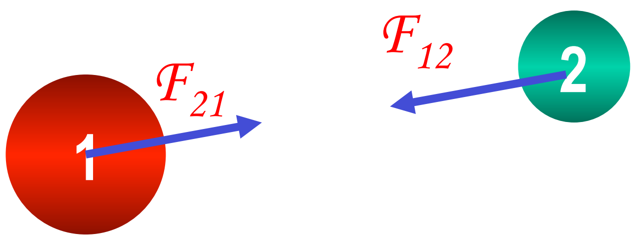
- Reminder for Term exam #1
  - In class Thursday, Sept. 25. Do NOT Miss the exam!
  - Covers CH1.1 through what we learn Tuesday Sept. 23 plus the math refresher
  - Mixture of multiple choice and free response problems
  - Bring your calculator but DO NOT input formula into it!
    - Your phones or portable computers are NOT allowed as a replacement!
  - You can prepare a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
    - None of the parts of the solutions of any problems
    - No derived formulae, derivations of equations or word definitions!

Special Project #3

- The mass of the spacecraft is 11,000 kg and the mass of the astronaut is 92 kg. What is the velocity of the space craft and the astronaut 10 sec into the motion if they were in contact for 50cm during with the astronaut is applying the force of 36N? (20 points)
- Deadline: Beginning of the class Tuesday, Sept. 30
- Please be sure to show details of your OWN work!

Newton's Third Law (Law of Action and Reaction)

If two objects interact, the force F_{12} that object 1 exerts on object 2 is equal in magnitude and opposite in direction to the force F_{21} object 2 exerts on object 1.



$$\boxed{\vec{F}_{12} = -\vec{F}_{21}}$$

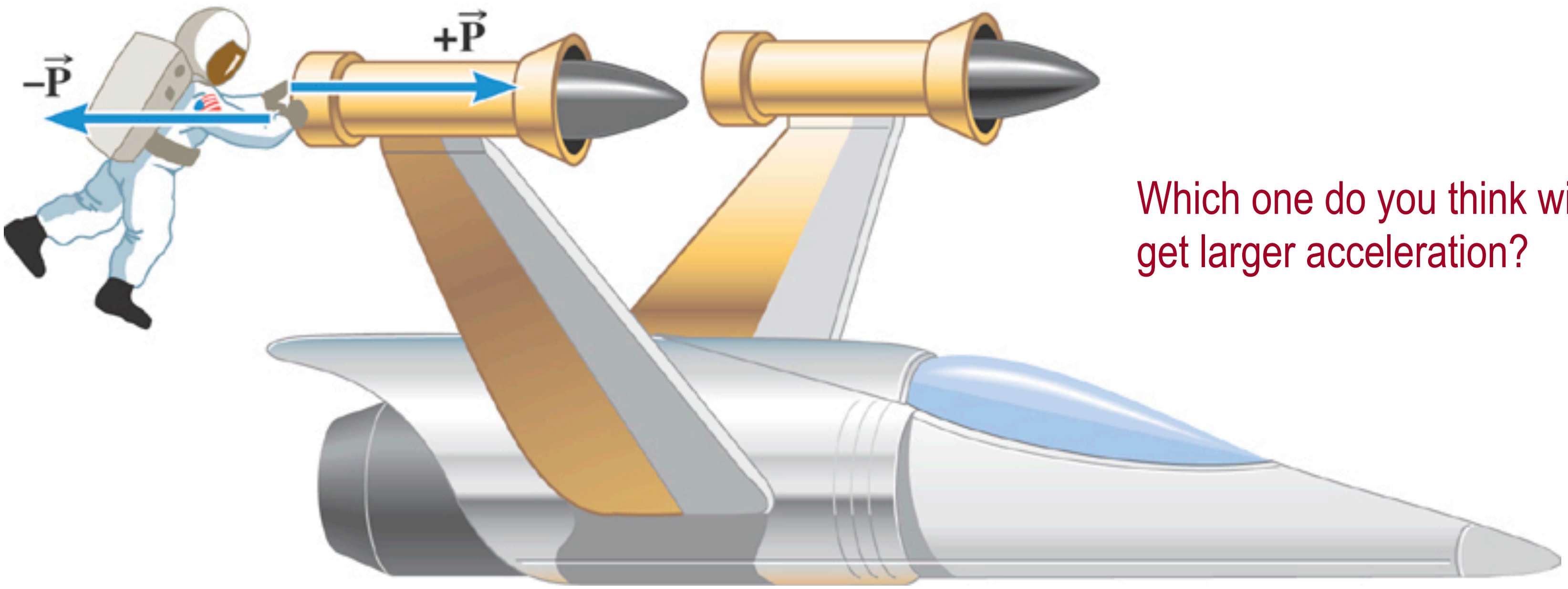
The reaction force is equal in magnitude to the action force but in opposite direction. These two forces always act ***on different objects.***

What is the reaction force to the force of a free falling object?

The gravitational force exerted by the object to the Earth!

Stationary objects on top of a table has a reaction force (called the normal force) from the table to balance the action force, the gravitational force.

Ex. The Accelerations Produced by Action and Reaction Forces



Which one do you think will get larger acceleration?

Suppose that the magnitude of the force P is 36 N. If the mass of the spacecraft is 11,000 kg and the mass of the astronaut is 92 kg, what are the accelerations?

Ex. continued

Force exerted on the space craft by the astronaut $\sum \vec{\mathbf{F}}_{AS} = \vec{\mathbf{P}}$

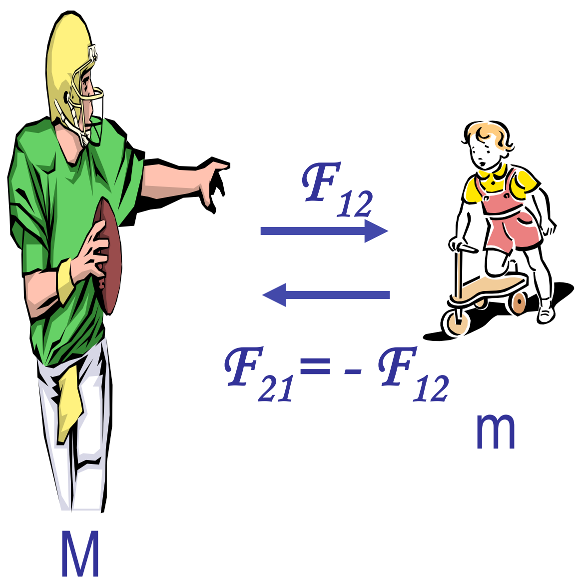
Force exerted on the astronaut by the space craft $\sum \vec{\mathbf{F}}_{SA} = -\vec{\mathbf{P}}$

space craft's acceleration
$$\vec{\mathbf{a}}_s = \frac{\vec{\mathbf{P}}}{m_s} = \frac{+36\ \vec{i}\ \mathrm{N}}{11{,}000\ \mathrm{kg}} = +0.0033\,\mathrm{m/s^2}$$

astronaut's acceleration
$$\vec{\mathbf{a}}_A = \frac{-\vec{\mathbf{P}}}{m_A} = \frac{-36\ \vec{i}\ \mathrm{N}}{92\ \mathrm{kg}} = -0.39\,\mathrm{m/s^2}$$

Example of Newton's 3rd Law

A large man and a small boy stand facing each other on **frictionless ice**. They put their hands together and push against each other so that they move apart. a) Who moves away with the higher speed and by how much?



$$\vec{F}_{12} = -\vec{F}_{21} \Rightarrow \left|\vec{F}_{12}\right| = \left|\vec{F}_{21}\right| = F$$

$$\vec{F}_{12} = m\vec{a}_b \Rightarrow F_{12x} = ma_{bx}, \quad F_{12y} = ma_{by} = 0$$

$$\vec{F}_{21} = M\vec{a}_M \Rightarrow F_{21x} = Ma_{Mx}, \quad F_{21y} = Ma_{My} = 0$$

Since $\vec{F}_{12} = -\vec{F}_{21}$ and $\left|\vec{F}_{12}\right| = \left|-\vec{F}_{21}\right| = F$

Establish the equation $\Rightarrow$ $ma_{bx} = F = Ma_{Mx}$ **Divide by m** $\Rightarrow$ $a_{bx} = \dfrac{F}{m} = \dfrac{M}{m}a_{Mx}$

Example of Newton's 3rd Law, cnt'd

Man's velocity

$$v_{Mxf} = v_{Mxi} + a_{Mx}t = a_{Mx}t$$

Boy's velocity

$$v_{bxf} = v_{bxi} + a_{bx}t = a_{bx}t = \frac{M}{m}a_{Mx}t = \frac{M}{m}v_{Mxf}$$

So boy's velocity is higher than man's, if M>m, by the ratio of the masses.

b) Who moves farther while their hands are in contact?

Boy's displacement

$$x_b = v_{bxi}t + \frac{1}{2}a_{bx}t^2 = \frac{M}{2m}a_{Mx}t^2$$

$$x_b = \frac{M}{m}\left(\frac{1}{2}a_{Mx}t^2\right) = \frac{M}{m}x_M$$

Man's displacement

Given in the same time interval, since the boy has higher acceleration and thereby higher speed, he moves farther than the man.

Categories of Forces

- Fundamental Forces: Truly unique forces that cannot be derived from any other forces
  - Total of three fundamental forces
    - Gravitational Force
    - Electro-Weak Force (the unified force of EM and Weak)
    - Strong Nuclear Force
- Non-fundamental forces: Forces that can be derived from fundamental forces
  - Friction
  - Tension in a rope
  - Normal or support forces

Gravitational Force and Weight

Gravitational Force, F_g

The attractive force exerted on an object by the Earth

$$\vec{F}_G = m\vec{a} = m\vec{g}$$

Weight of an object with mass M is

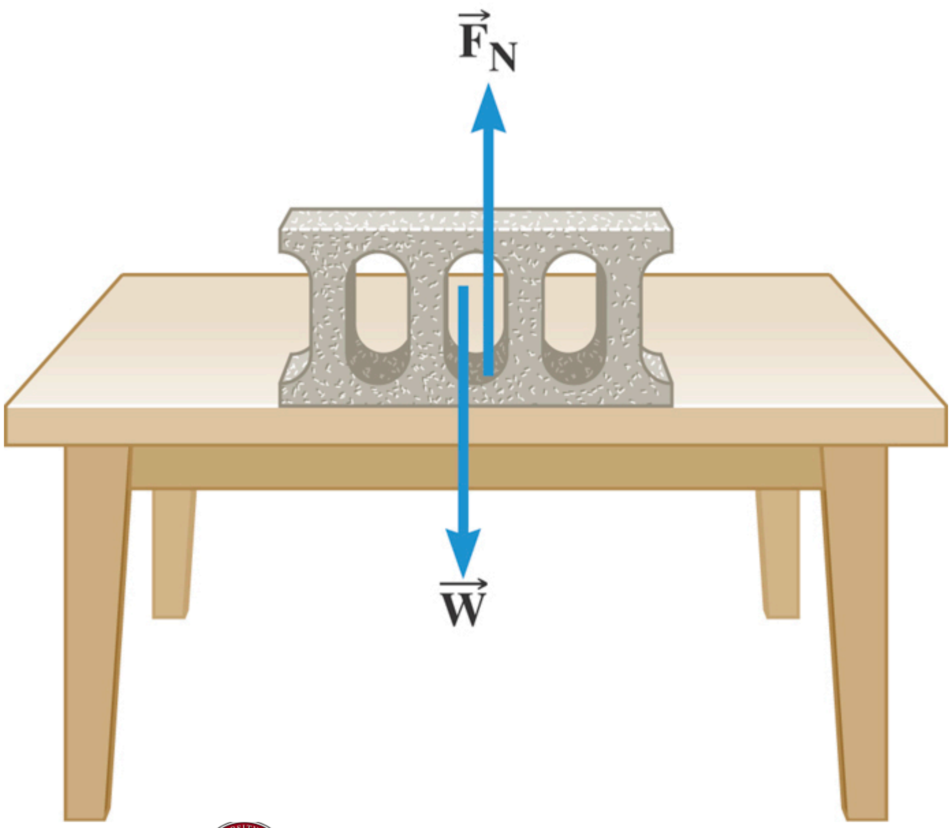
$$W = \left|\vec{F}_G\right| = M\left|\vec{g}\right| = Mg$$

*Since weight depends on the magnitude of gravitational acceleration, **g**, it varies depending on geographical location.*

By measuring the forces one can determine masses. This is why you can measure mass using the spring scale.

The Normal Force

The normal force is one component of the force that a surface exerts on an object with which it is in contact – namely, the component that is **perpendicular to the surface**.

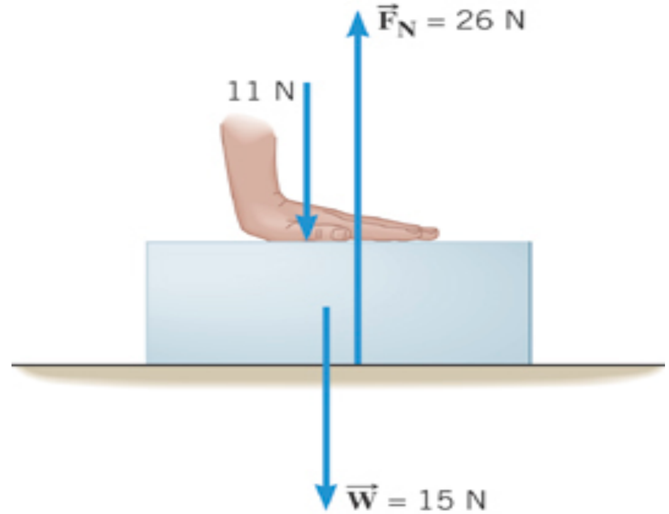


Some normal force exercises

Case 1: Hand pushing down on the book

$$F_N - 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 26\text{ N}$$

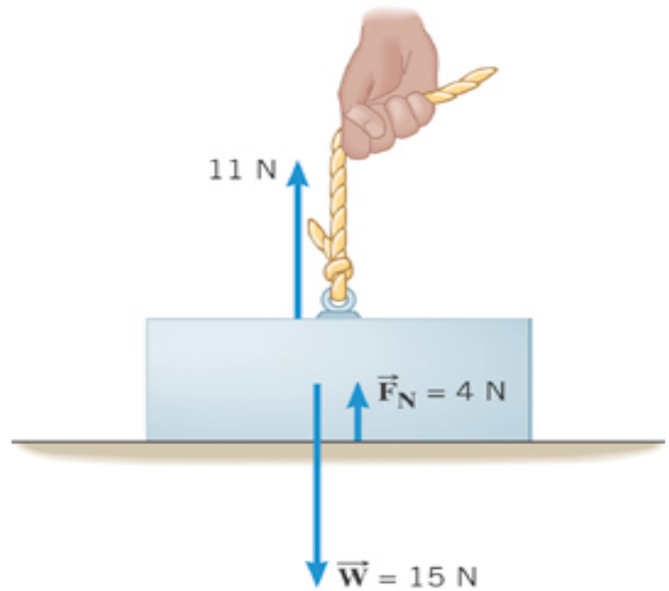


(a)

Case 2: Hand pulling up the book

$$F_N + 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 4\text{ N}$$



(b)

Some Basic Information

When Newton's laws are applied, *external forces* are only of interest!!

Why?

Because, as described in Newton's first law, an object will keep its current motion unless non-zero net external force is applied.

Normal Force, n:

Reaction force that reacts to action forces due to the surface structure of an object. Its direction is perpendicular to the surface.

Tension, T:

The reactionary force by a stringy object against an external force exerted on it.

Free-body diagram

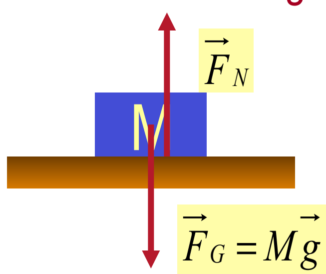
*A graphical tool which is a **diagram of external forces on an object** and is extremely useful analyzing forces and motion!! Drawn only on an object.*

Free Body Diagrams and Solving Problems

- Free-body diagram: A diagram of vector forces acting on an object
- A great tool to solve a problem using forces or using dynamics

1. Select a point on an object in the problem
2. Identify all the forces acting only on the selected object
3. Define a reference frame with positive and negative axes specified
4. Draw arrows to represent the force vectors on the selected point
5. Write down net force vector equation
6. Write down the forces in components to solve the problems

- No matter which one we choose to draw the diagram on, the results should be the same, as long as they are from the same motion

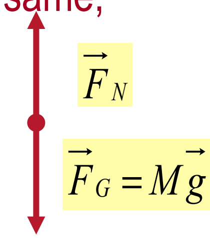


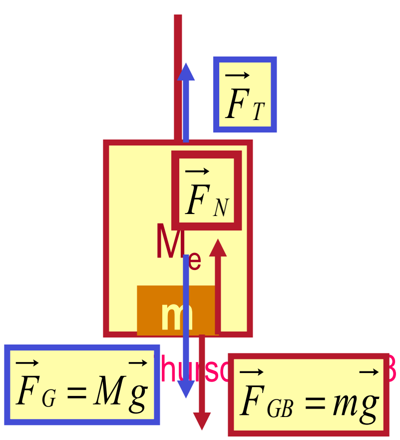
Which one would you like to select to draw FBD?

What do you think are the forces acting on this object?

Gravitational force

the force supporting the object exerted by the floor



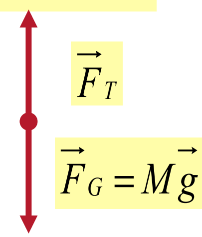


Which one would you like to select to draw FBD?

What do you think are the forces acting on this elevator?

Gravitational force

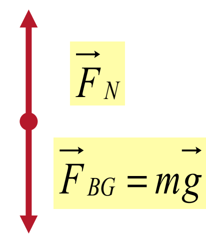
The force pulling the elevator (Tension)



What about the box in the elevator?

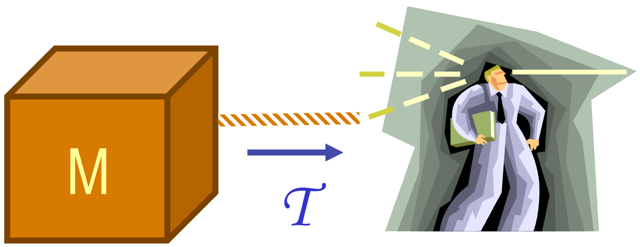
Gravitational force

Normal force



Applications of Newton's Laws

Suppose you are pulling a box on frictionless ice, using a rope.



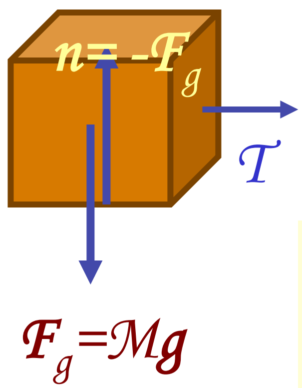
What are the forces being exerted on the box?

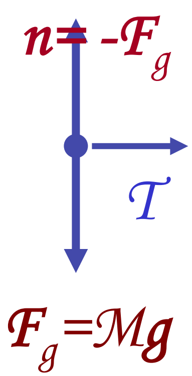
Gravitational force: $\boldsymbol{F}_g$

Normal force: $\boldsymbol{n}$

Tension force: $\boldsymbol{T}$

Free-body diagram





Total force:
$\boldsymbol{F} = \boldsymbol{F}_g + \boldsymbol{n} + \boldsymbol{T} = \boldsymbol{T}$

$$\sum F_x = T = Ma_x \qquad \boxed{a_x = \frac{T}{M}}$$

$$\sum F_y = -F_g + n = Ma_y = 0 \qquad \boxed{a_y = 0}$$

If T is a constant force, a_x, is constant

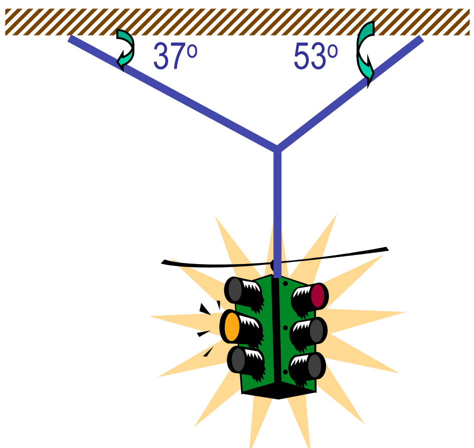
$$v_{xf} = v_{xi} + a_x t = v_{xi} + \left(\frac{T}{M}\right)t$$

$$\Delta x = x_f - x_i = v_{xi}t + \frac{1}{2}\left(\frac{T}{M}\right)t^2$$

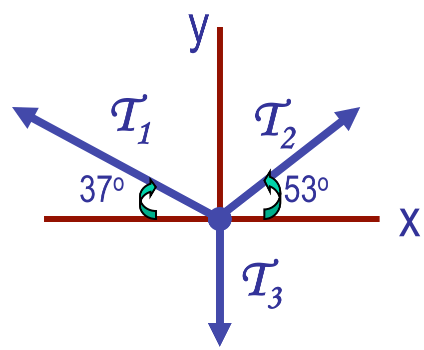
What happened to the motion in y-direction?

Example for Using Newton's Laws

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support. The upper cables make angles of 37.0^o and 53.0^o with the horizontal. Find the tension in the three cables.



Free-body Diagram



$$\vec{F} = \vec{T}_1 + \vec{T}_2 + \vec{T}_3 = m\vec{a} = 0$$ Newton's 2nd law

x-comp. of net force

$$F_x = \sum_{i=1}^{i=3} T_{ix} = 0 \quad -T_1\cos(37^\circ) + T_2\cos(53^\circ) = 0 \therefore T_1 = \frac{\cos(53^\circ)}{\cos(37^\circ)} T_2 = 0.754 T_2$$

y-comp. of net force

$$F_y = \sum_{i=1}^{i=3} T_{iy} = 0$$

$$T_1 \sin(37^o) + T_2 \sin(53^o) - mg = 0$$

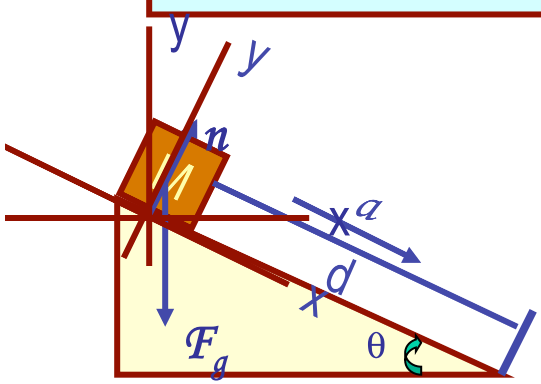
$$T_2\left[\sin(53^\circ) + 0.754 \times \sin(37^\circ)\right] = 1.25 T_2 = 125N$$

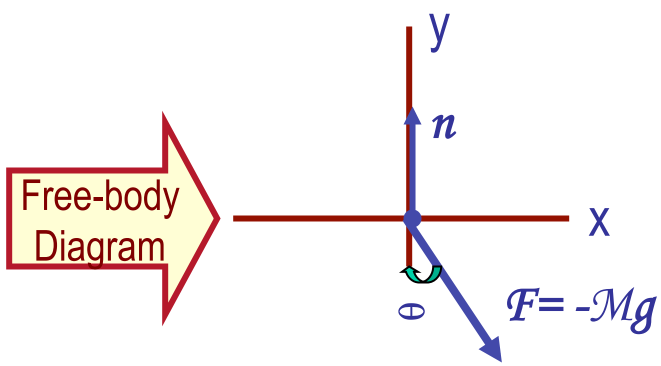
$$T_2 = 100N; \quad T_1 = 0.754 T_2 = 75.4N$$

Example w/o Friction

A crate of mass M is placed on a frictionless inclined plane of angle θ.

a) Determine the acceleration of the crate after it is released.





$$\vec{F} = \vec{F}_g + \vec{n} = m\vec{a}$$

$$F_x = Ma_x = F_{gx} = Mg\sin\theta$$

$$\boxed{a_x = g\sin\theta}$$

$$F_y = Ma_y = n - F_{gy} = n - mg\cos\theta = 0$$

Supposed the crate was released at the top of the incline, and the length of the incline is d. How long does it take for the crate to reach the bottom and what is its speed at the bottom?

$$d = v_{ix}t + \frac{1}{2}a_x t^2 = \frac{1}{2}g\sin\theta\, t^2$$

$$\boxed{\therefore t = \sqrt{\frac{2d}{g\sin\theta}}}$$

$$v_{xf} = v_{ix} + a_x t = g\sin\theta\sqrt{\frac{2d}{g\sin\theta}} = \sqrt{2dg\sin\theta}$$

$$\boxed{\therefore v_{xf} = \sqrt{2dg\sin\theta}}$$

Work on sample problem 5.03 on page 108!