Lesson 7

Newton's Three Laws of Motion

I. Inertia

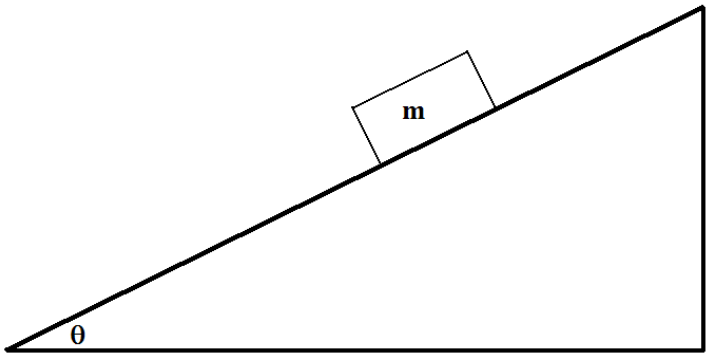
II. $\sum \vec{F} = m\vec{a}$

III. Action vs. Reaction

We have learned how to draw vectors and how to add them both graphically and mathematically. Also, we covered linear and non-linear motion equations, how "acceleration", "velocity", and "position" are related. If one of the three is known, we can derive others. Newton's three laws connect between "Forces" and "motions". To change a system's "velocity", it has to have "acceleration" and "acceleration" can be given to the system by only "non-zero outside force". "Internal force" does not cause any velocity change. Therefore, we need to able to recognize "outside forces" (graphically), add those vectors (by breaking them into components), and calculate "acceleration" (Newton's Second Law) so that we can build velocity and position functions.

Example 1 – Block on an inclined plane

There is a block sitting on a frictionless inclined plane.



(a) Calculate acceleration of the block.

Let m = 3 kg and $\theta = 30^0$.

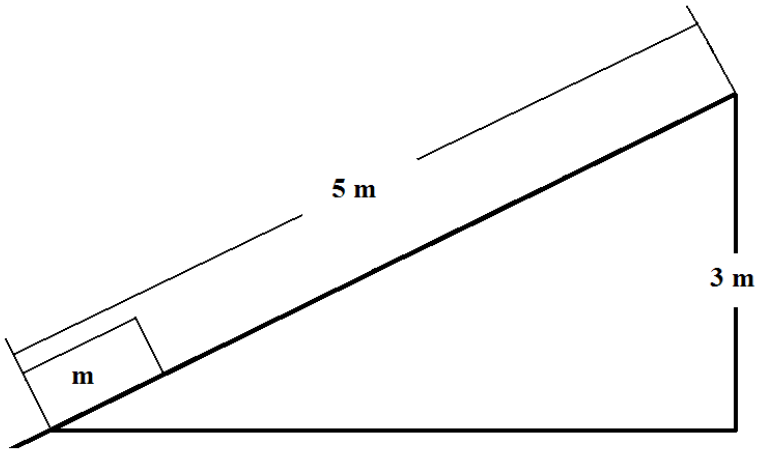
(b) What is the speed of the block at t = 6 sec?

(c) When the block is moving at 6 m/sec, how far did it slide?

(b) What is the speed of the block when it slides 5 m?

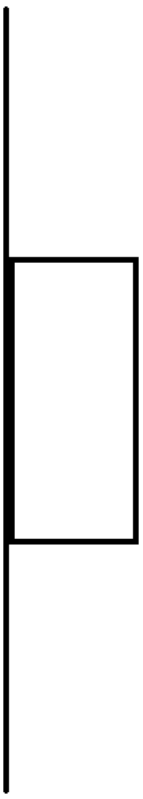
Example 2 – Block on an inclined plane (upward)

A block begins moving upward v_0 = 20 m/sec on a frictionless inclined plane for 5 m. Then, it becomes a projectile. What is the range? See the diagram on the right for clarification.



In the real world, it is very difficult to obtain a frictionless inclined plane. Usually, it comes with friction. So, it is a good time to start including "frictional force".

Let's say the diagram you see on the right is a cross-sectional picture of a black board and an eraser. How many forces are acting on the eraser if:



(a) Nothing is done

(b) You push it into the board so that it stays on the board.

(c) You push it in even harder than (b)

(d) You push it in less than (c), yet it does not move

What is interesting here is that somehow, friction is created by the normal force, which is perpendicular to the force of friction.

Rules

1. Friction is always applied to the opposite direction of motion at the given time or opposite of direction of acceleration if it is not moving.
2. Friction is applied as much as it needs to stop up to the maximum friction.
3. Maximum friction is proportional to the normal force.

$F_{fric} = \mu_s N$ (For static)

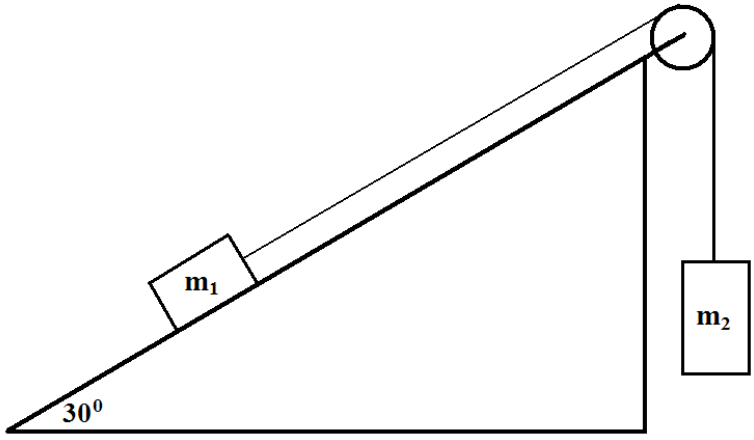
$= \mu_k N$ (For kinetic), where μ_s is coefficient of static friction and μ_k is coefficient of kinetic friction. They are decided by the two materials rubbing each other. Smallest coefficient is 0 (no negative coefficient). Tires and cement is 1 when dry and less than 1 when wet. 1 is not the largest number, but it can be higher.

Example 3

Go back to the examples 1 and 2 with frictions (let $\mu_s = 0.3$) and try to answer the questions.

Example 4

Two blocks are connected by a massless string. m_1 is on an inclined plane and m_2 is suspended. Initially, the system is not moving. If $m_1 = 10$ kg, $m_2 = 6$ kg, and $\mu_s = \mu_k = 0.01$, what is the acceleration of the system?



To solve this problem, the steps are very similar to what we already covered.

Now, draw forces acting on m_1 and m_2.

If you hesitate and stop for m_1, you are thinking correctly. This is because we don't know the direction of friction. One possible method is that you can guess the direction of friction and try to solve;

(a) What if the solution of "a" is positive, what does it mean physically?

(b) What if the solution of "a" is negative, what does it mean physically? What do you have to do next?

(b-1) What if the new solution of "a" is positive, what does it mean physically?

(b-2) What if the new solution of "a" is negative, what does it mean physically?

As you can see from the questions above, the worst case is (b-2). This will be a total waste of time especially during a quiz or an exam. Hence, you don't want to employ this method of guessing.

You can save time by doing a simple check – Initial test. This is to check the natural direction of the system when there is no friction. Once we know the direction of acceleration without friction, the direction of friction is <u>always</u> the opposite. Therefore, we can build force equations without guessing.

(c) What if the solution of "a" is negative, what does it mean physically?

Now, do the initial test and establish correct force equations so that you can solve for "a".

The pictures below are before and during take-off of a jumbo jet 777. As you can see, before take-off, the weight is straight down, but is tilted during take-off. Using the counter behind as a vertical reference line, estimate the plane's acceleration. At the take-off, the mass of the plane is 347,450 kg (for detail specs, see http://en.wikipedia.org/wiki/Boeing_777). There are two engines on the plane. Calculate the thrust (force) of each engine. (According to the specification, the thrust of each engine to be 480 KN and it, of course is the maximum thrust so you may not get the exact value.) – Pictures taken by Noga-shook,Rene E