Workshop Tutorials for Introductory Physics

Solutions to MI4: **Newton's Laws I**

A. Review of Basic Ideas:

Forces

How can a tugboat pull a cruise ship that's much heavier than the tug? Why does it take a long distance to stop the ship once it is in motion? Why is it harder to control a car on an icy road than on dry concrete? The answers to these and similar questions take us into the subject of dynamics, the relationship of motion to the **forces** that cause it. We will use kinematic quantities; displacement, **velocity** and acceleration, to understand what makes bodies move the way they do.

All the principles of dynamics can be wrapped up in a neat package containing three statements called Newton's laws of motion. The first law states that when the net force on a body is **zero,** its motion doesn't change. The second law relates force to acceleration when the net force is not zero. The third law gives a relation between the forces that two interacting bodies exert on each other. Many other scientists before Newton contributed to the foundations of mechanics, including Copernicus, Brahe, Kepler and Galileo Galilei. Indeed, Newton himself said, "If I have been able to see a little farther than other men, it is because I have stood on the shoulders of giants."

The concept of force gives a **quantitative** description of the interaction between a system and its environment. There are forces, including **gravitational** and electrical forces, that act even when the bodies are separated by empty space. Force is a **vector** quantity; to describe a force we need to describe the direction in which it acts as well as its magnitude. The SI unit of the magnitude of force is the **newton**, abbreviated N.

Discussion Questions

If a car is stationary then it will not move unless there is a net force acting on it. If it is already rolling it will continue to do so at the same rate unless a net force acts.

B. Activity Questions:

1. Gaining Weight

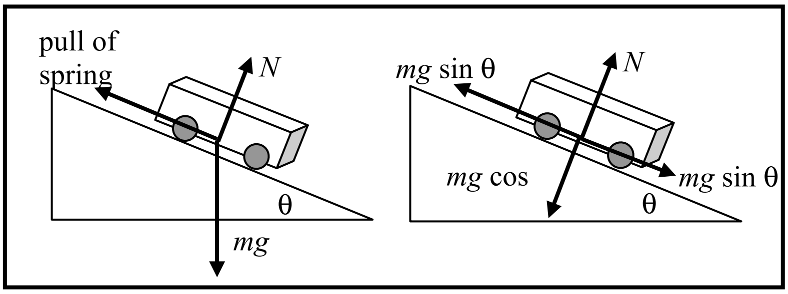
A bathroom scale measures the force applied to it. They are calibrated to display mass (mislabeled weight).You cannot change and hold the reading without touching anything else.

You can change (and hold) the reading while holding a friend. You can push down on your friend so that they take some of your weight, and the scale will read lower. If your friend pushes you down, or you push upwards on your friend, the force exerted on the scale is greater and it reads a higher weight.

If you stand with your weight evenly distributed over two bathroom scales they will each read half your weight (really your mass), as half your weight force due to gravity is applied to each scale.

If you shift your weight to your right leg the scale under your right foot will read more, and the scale under your left foot will read less, as the weight force is redistributed.

2. A variable ramp with stationary trolley



With no friction the force needed to keep the trolley on the ramp is a component of the weight: $mg\sin\theta$. The spring balance may read a little less than this as friction is also acting to prevent the trolley rolling down due to gravity.

As the angle of inclination, θ, is increased the force needed to hold the trolley increases, reaching a maximum of mg when $\theta = 90^o$.

3. Constant velocity

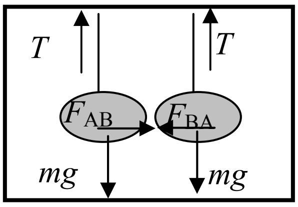
To pull a trolley up a ramp at constant speed we need to apply a constant force of $mg\sin\theta$ so that the net force is zero (ignoring friction). N balances the component of mg perpendicular to N, which is $mg\cos\theta$, so the pull must be equal to the component of gravity $mg\sin\theta$. On a flat surface the net force acting to give a constant velocity is zero. Hence at constant velocity the spring balance will read close to zero. On a flat surface we need just enough force to oppose frictional forces. There is always some friction, the force required to pull the trolley at constant velocity will be equal to the frictional force acting on it.

4. Constant acceleration

When the trolley accelerates down the ramp it is not in equilibrium. The unbalanced force is the component of gravity parallel to the ramp

5. Newton's Cradle (2 balls.)

When one ball is held out and released it swings back, hitting the second ball and causing it to swing out. The action–reaction pair is the force of ball A on ball B and the force of ball B on ball A, F_{AB} and F_{BA}.



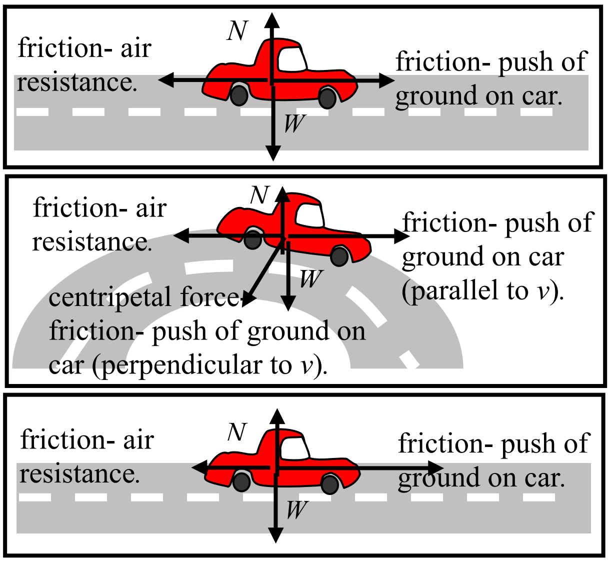
C. Qualitative Questions:

1. Force on a car in different situations.

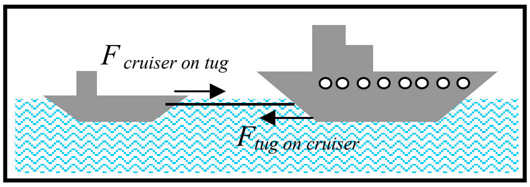
a. A car cruising at constant speed in a straight line is not accelerating, and hence experiences no net force. All the forces acting on it, for example air resistance and the frictional force of the ground, add to zero.

b. A car going around a corner at constant speed accelerating, and hence experiences a net force in towards centre of the curve.

c. A car accelerating in a straight line experiences a net force. In this case, air resistance is less than the frictional force of the ground on the car.



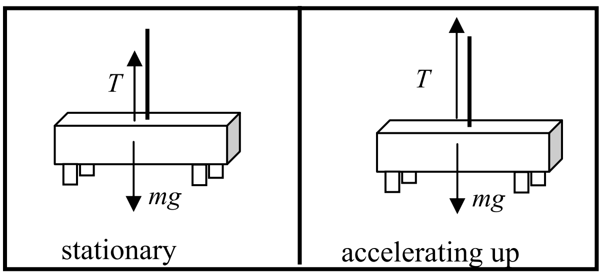
2. The force which the cruise ship applies to the tug boat does not affect the cruise ship because it is not applied to the cruise ship. The force applied by the tug to the cruise ship does accelerate it. Action–reaction force pairs act on *different objects*.



D. Quantitative Question:

a. The maximum tension in rope = 2000 N.

(Assume a frictionless pulley and mass-less rope.) The maximum pulling force is 2000 N because this is the maximum the rope can sustain. This force is transmitted through the rope to pull on the piano. So a force acting at an angle is transferred into an upward force via the pulley.



b. There are no forces acting in the horizontal direction on the piano. In the vertical direction the forces acting are T and mg. If piano is stationary (but off the ground) or moving with uniform velocity then $T = mg$. For an accelerating piano there must be a net force; $F = T - mg = ma$. Rearranging for a:

$a = (T\text{-}mg)/m = (T/m\ ) - g = (2000\text{ N} / 150\text{ kg}) - 9.8\text{ m.s}^{-2} = 3.5\text{ m.s}^{-2}$ (upwards).