

Workshop Tutorials for Introductory Physics

Solutions to MI5: Newton's Laws II – Frictional Forces

A. Review of Basic Ideas:

Friction

When you're driving a car at **constant** speed all the petrol or gas you're burning is being used just to overcome frictional forces, such as air **resistance** and friction in the moving parts of the car. Friction is due to the interaction between **atoms** on the surfaces of materials. Even what looks like a very smooth surface, such as glass or polished metal, is actually very **lumpy** on a microscopic scale.

When you first try to slide one surface across another you have to break many bonds. The force which prevents the surfaces sliding is the **static** frictional force, f_s . As the surfaces slide past each other there is a continuous tearing and **reforming** of bonds as chance contacts are made. The **kinetic** friction, f_k , is the sum of the forces due to these contacts. Sometimes the surfaces briefly stick together then slip, giving a jerky motion, which can produce squeaking or squealing.

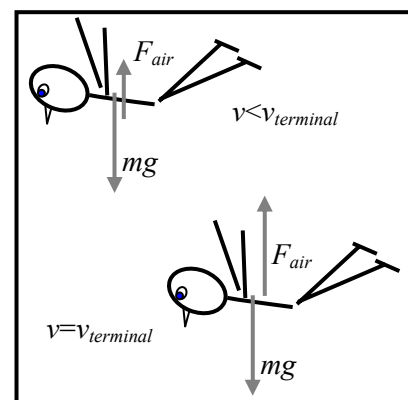
Consider a block sitting on a surface. The **maximum** magnitude of f_s is $f_{smax} = \mu_s N$, where N is the **normal** force. The direction of f_s is always parallel to the surface and opposite to the component of applied force parallel to the surface. Once the block starts to move the frictional force decreases to the kinetic frictional force, which is given by $f_k = \mu_k N$. The constants μ_s and μ_k are called the **coefficients** of friction and are determined **experimentally**. They depend on the properties of the two surfaces, and we usually assume that they don't depend on the speed of the sliding. In contrast, air resistance does depend on the velocity of the moving object.

Around 20% of the petrol used by a car is used just to overcome friction in the moving parts, and oil companies spend a fortune developing new and better **lubricants**. But friction is also necessary to drive the car at all. If there was no friction between the tyres and the road the wheels would spin on the spot and the car wouldn't go anywhere. And you wouldn't be able to go for help without friction, because you couldn't walk if there was no friction between your **feet** and the ground.

Discussion questions.

See diagram opposite. At terminal velocity $F_{air} = mg$. If air resistance didn't increase with increasing speed, sky divers would never reach a terminal velocity. They would continue to accelerate, and the heights from which they could jump would be limited by this.

In a tug of war it is the frictional force between the ground and a team's shoes that determine how hard they can pull, and how much of a pull from the other team they can withstand.



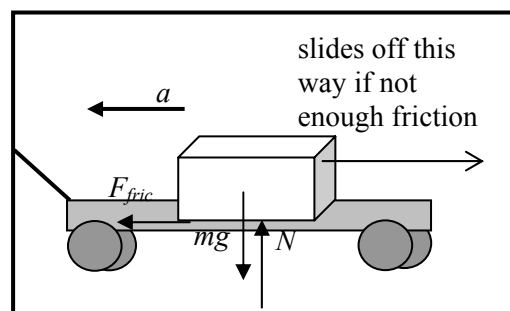
B. Activity Questions:

1. Shoes

Shoes with spiked soles, such as football boots are designed to help grip soft slippery surfaces, for example a muddy playing field. Sneakers and running shoes are also designed to grip, but do not have spikes as they are generally used on hard surfaces which are not as slippery as mud. Dancing shoes usually have smooth soles so that the wearer can slide a bit, but not too much. Dancers often put talc on their shoes (as weight lifters do on their hands) to give themselves a bit more grip.

2. Boxes on a trolley

All boxes slip off together. If the trolley is accelerated forwards the boxes slip backwards, if it is decelerated the boxes slip forwards. The rougher the surfaces, the harder it is for slipping to occur, i.e. slipping occurs at a greater acceleration. The acceleration of the truck and μ , the coefficient of friction between the trolley and the box, determine if the box slips or not. The mass of the boxes don't affect their slipping.

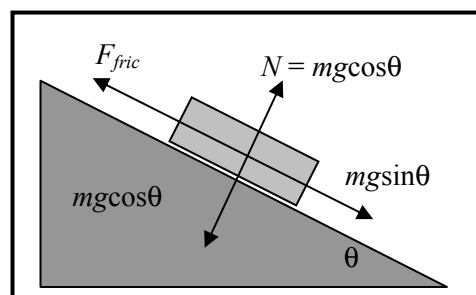


3. Block on a rough variable ramp

Consider forces up and down the inclined plane. Just before slipping the forces up the ramp (frictional forces) must be equal to the forces down the ramp (component of weight), so

$$F_{\text{fric}} = \mu mg \cos \theta = mg \sin \theta \text{ and } \mu = \tan \theta$$

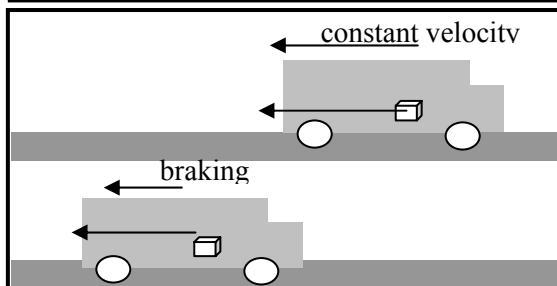
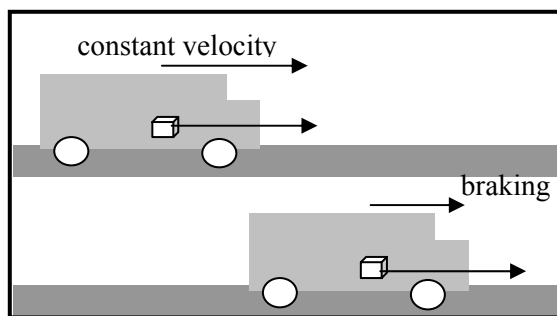
If the F_f is greater (a rough surface), the angle for slipping is larger. A smoother ramp gives a smaller angle for slipping.



C. Qualitative Questions:

1. The case will only go backwards if the bus is accelerating forwards. A suitcase cannot fly backwards if the bus is moving forwards at constant speed or braking. If there is not enough friction to slow the case along with the bus then as the bus slows the case will continue to move forwards. At constant speed there is no net force on the bus or case, and the case will not move relative to the bus. Hence the passengers claim cannot be true if the bus was going forwards and braking.

A suitcase may fly towards the rear if a reversing bus decelerates. When the driver slams on the brakes the suitcase will continue to move backward, unless the force of friction between the case and the bus is enough to accelerate it along with the bus.



2. Box on a truck.

a. See diagram opposite.

b. The box (the system) will move along with the truck, which is to the left unless the truck is reversing.

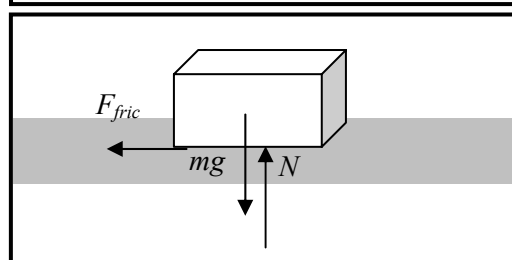
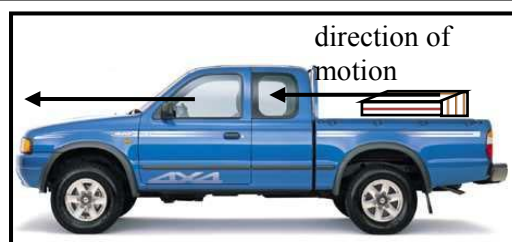
c. If the tray and box are very smooth the box will slide off as the truck moves away, i.e. if there is not enough friction.

d. The forces acting on the system (the box) are the weight force, mg , the normal force, N , and the frictional force of the truck's tray on the box.

e. The net force is the frictional force, which is to the left. The box is accelerating to the left, hence the net force **must** be to the left.

f. The acceleration is in the direction of the net force.

g. The only force acting in the horizontal direction is friction, this is the force which accelerates the box.



D. Quantitative Question:

a. In the vertical direction: $mg = -N$ or $mg + N = 0$.

In the horizontal direction: $F_{\text{fric}} = \text{net force} = ma$.

Using $F_{\text{fric}} = \mu N = ma$, the maximum acceleration is

$$a_{\text{max}} = \mu N / m = \mu mg / m = \mu g.$$

b. The box moves 1.2 m, while accelerating from 10 m.s^{-1} to 0 m.s^{-1} .

The acceleration can be found using $v^2 = v_o^2 + 2ax$.

Rearranging: $a = \frac{1}{2} (v^2 - v_o^2) / x = \frac{1}{2} (0 - (10 \text{ m.s}^{-1})^2) / 1.2 \text{ m} = 42 \text{ m.s}^{-2}$

The net force is $F = ma = \mu_k mg$. Rearranging for μ gives:

$$\mu_k = a/g = 42 \text{ m.s}^{-2} / 9.8 \text{ m.s}^{-2} = 4.3$$

