Motion and Friction

Dr. M. Imran Malik

School of Electrical Engineering & Computer Science
National University of Sciences & Technology (NUST), Pakistan

What is friction?

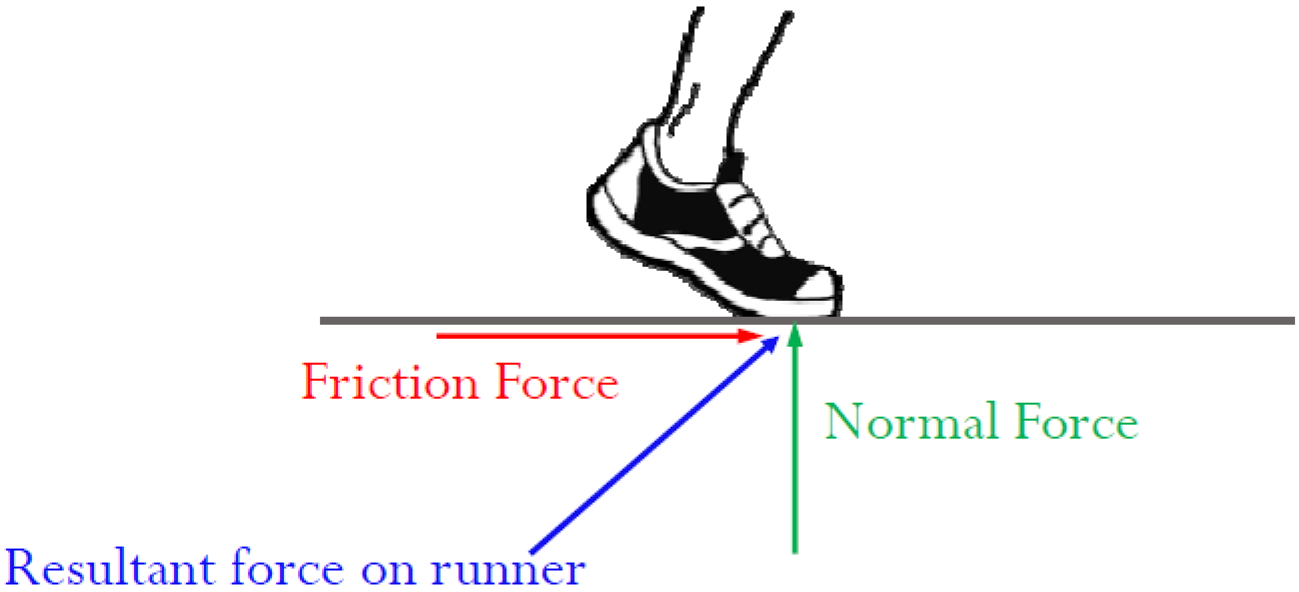
- Friction is a force
- A frictional force arises when two substances contact each other.
- The molecules of each surface interact according to Newton's Laws of Motion.
- Friction always opposes motion, i.e., it is opposite to the direction of velocity.

When an object is in motion either on a surface or in a viscous medium such as air or water, there is resistance to the motion because the object interacts with its surroundings. We call such resistance a force of friction.

Contact Force

- Force that occurs between objects that are in contact with each other.
- Contact forces can be resolved into components that are perpendicular and parallel to the surfaces in contact.
- The perpendicular component is called the **normal force**.
- The parallel component is called **friction**.

Contact Force in Running

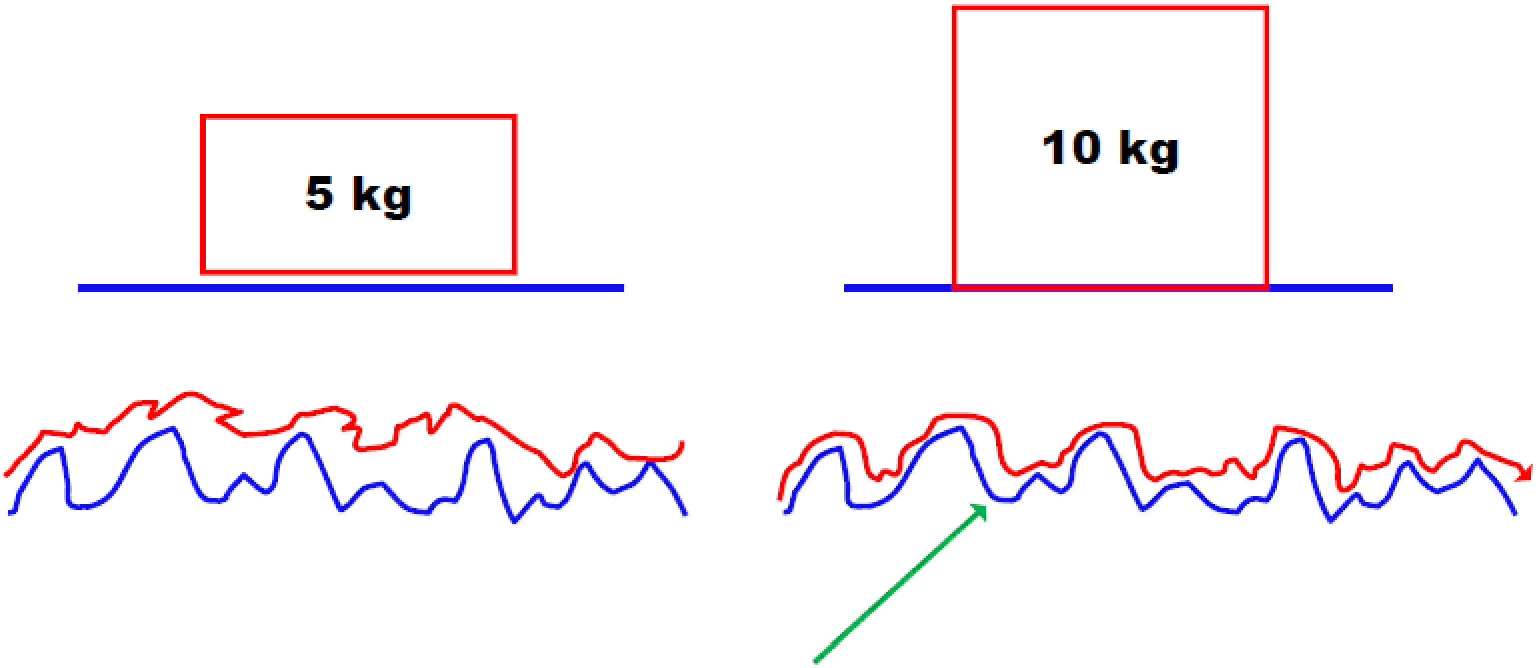


During the push off phase in running, the normal force acts upward on the runner, while the friction force acts forward on the runner. The frictional force is the only force capable of moving the runner horizontally down the track. The normal force can only accelerate the runner upwards.

Friction and the Normal Force

- The maximum frictional force is proportional to the normal contact force.
- An increase in the normal force results in an increase in the maximum friction.
- This is because the molecules on the two surfaces are pushed together more, thus increasing their interactions.

Increased Weight, Increased Normal Force, and Increased Friction

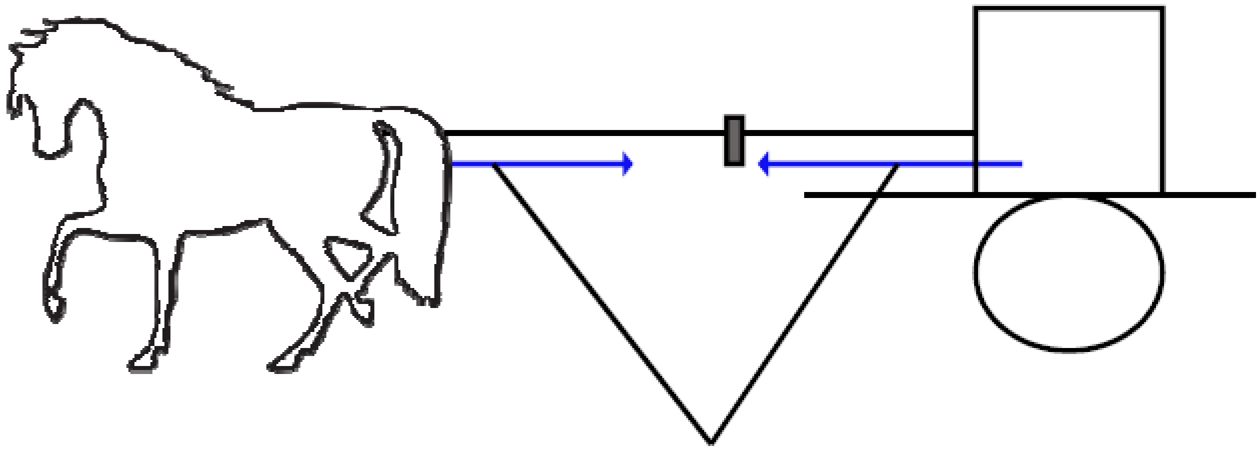


Surfaces are more compressed together and there are more interactions between molecules

Friction and Surface Area

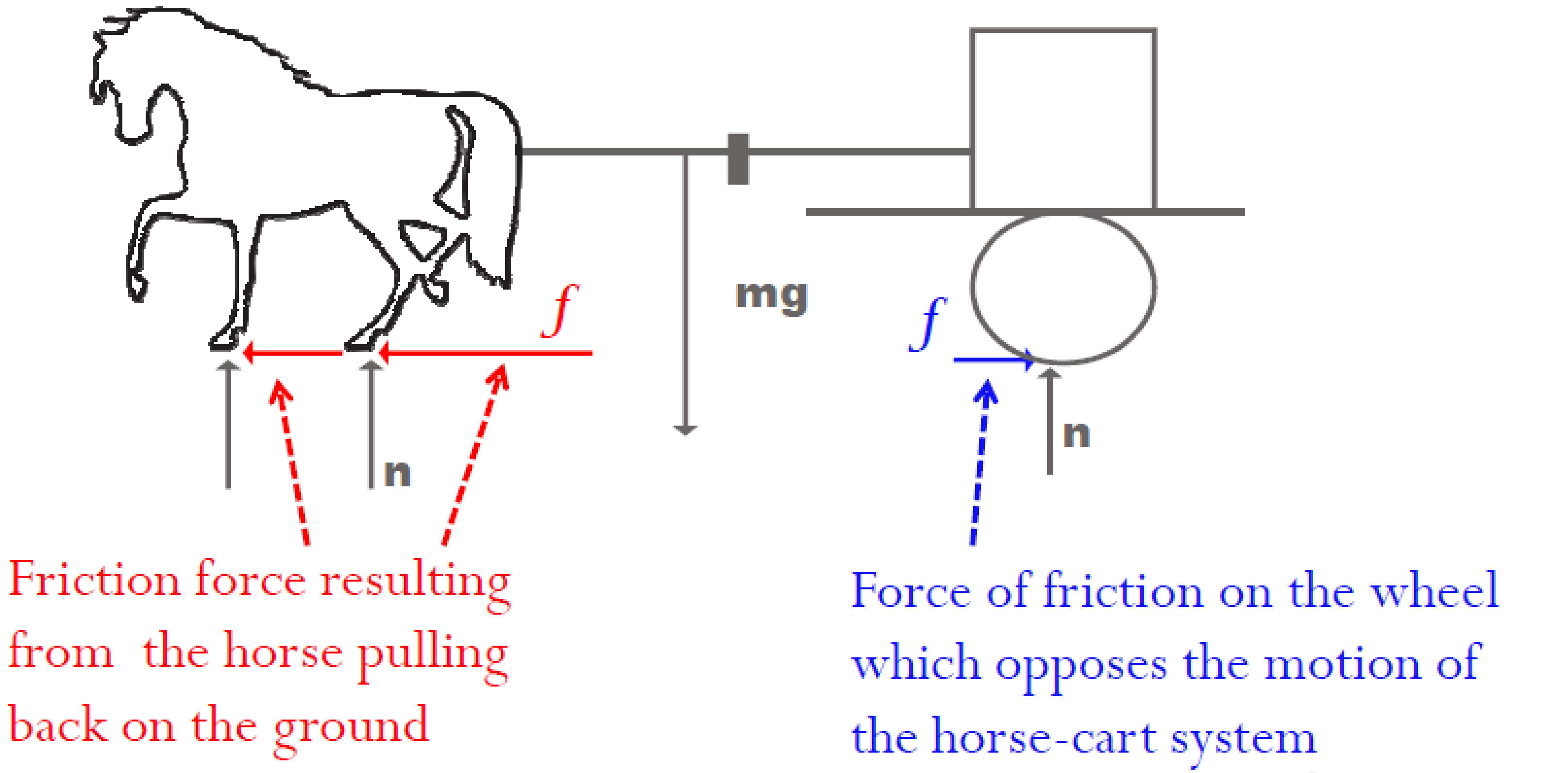
- Friction is not affected by the size of the surface area in contact.
- If the normal force remains constant, but the contacting surface area is increased, then the normal force is spread out over more molecules, thus the force on each molecule is reduced.

Horse Pulling Cart



According to Newton's 3rd Law, these forces are equal and opposite. So, if the horse pulls forward on the cart with the same force as the cart pulls back on the horse, how will the horse ever move the cart?

Friction acts on the horse's feet but very little acts on the wheels of the cart. Drawing a free body diagram reveals the answer. The horse and cart are one system so the forces in between them are internal and cannot produce a change in motion of the system.



Static and Kinetic Friction

- The force that counteracts applied force and keeps the object from moving is called the force of static friction *fs* .
- The friction force for an object in motion is called force of kinetic friction *fk*.
- Experimentally, we find that, to a good approximation, both *fs* and *fk* are proportional to the magnitude of the normal force.

$$f_{s\,\max} = \mu\, \mathrm{n}$$

- $f_{s\,\max}$ is the maximum force of friction.
- μ is the coefficient of friction (μ_{static} or $\mu_{kinetic}$).
- **n** is the normal force.

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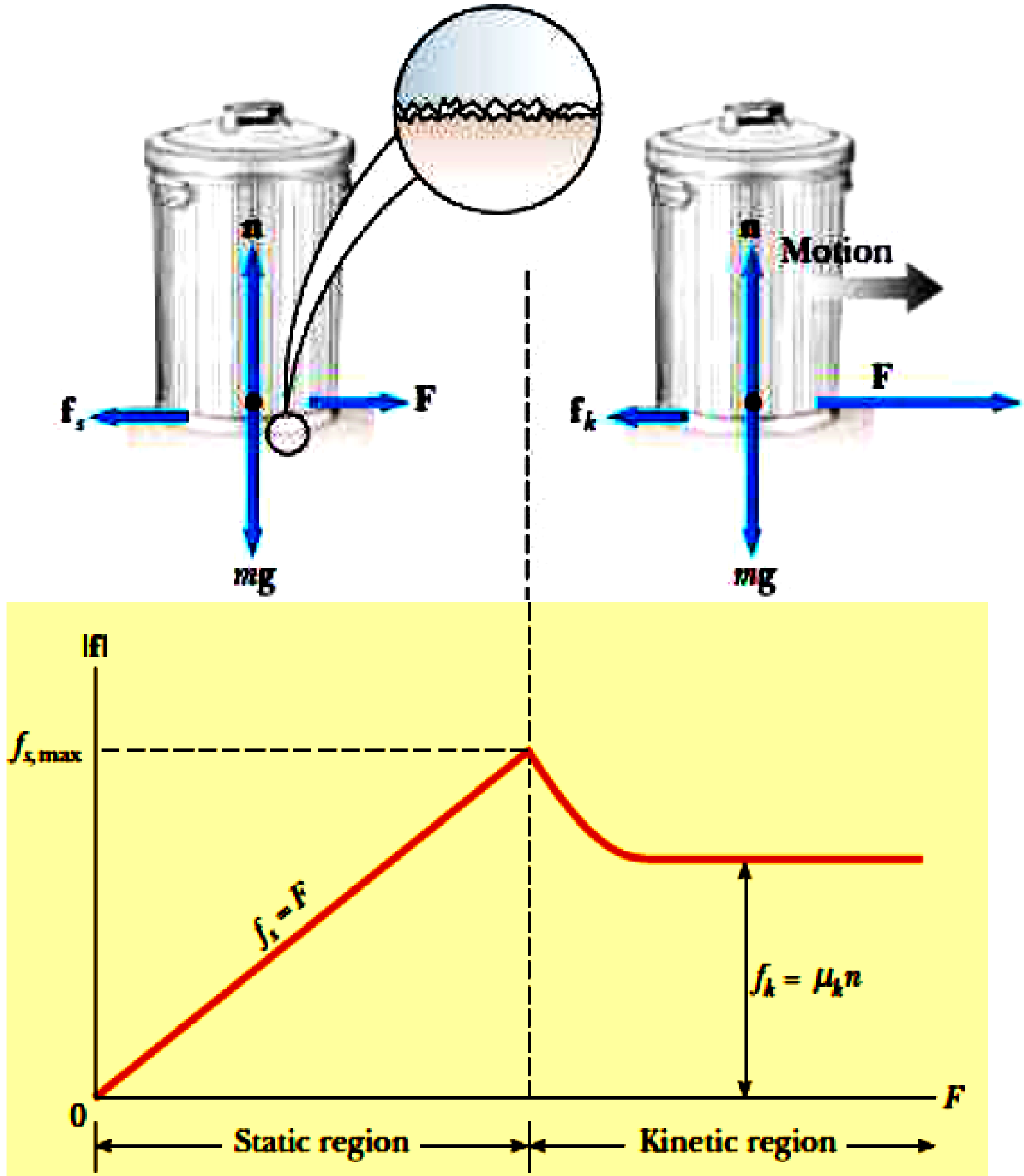

n
mg
fs
F
n
Motion
F
fk
mg
|f|
fs, max
fs = F
fk = μk n
0
F
Static region
Kinetic region

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Coefficient of Friction

μ depends on the types of surfaces that are interacting. It also depends on whether the surfaces are moving relative to each other or not (μ_{static} or $\mu_{dynamic}$).

$$\mu_k < \mu_s$$

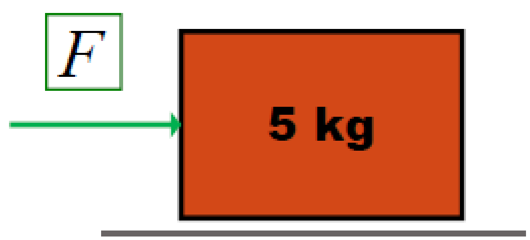
$$f_s \leq \mu_s \, n$$

$$f_k = \mu_k \, n$$

Coefficients of Friction[a]

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

A 5 kg block of wood rests on a ceramic counter. If the coefficient of static friction between the block and the counter is 0.4, what horizontal force is necessary to move the block.



According to Newton's laws

$$F - f = 0$$

$$n - mg = 0$$

Block is static, so

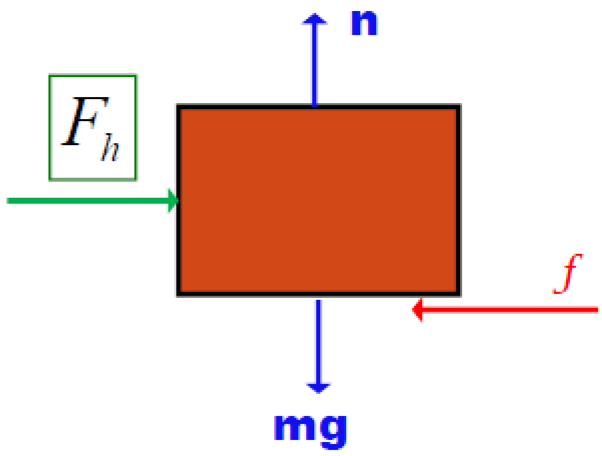
$$F - f_s = 0$$

$$F = \mu_s n \qquad \therefore f_s = \mu_s \text{ n}$$

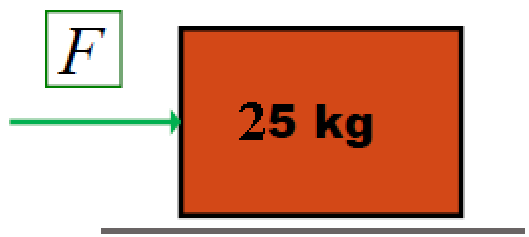
Max. static friction

$$F = \mu_s mg$$

$$F = 0.4(5)(9.8) = 19.5$$



A 25.0-kg block is initially at rest on a horizontal surface. A horizontal force of 75.0 N is required to set the block in motion. After it is in motion, a horizontal force of 60.0 N is required to keep the block moving with constant speed. Find the coefficients of static and kinetic friction from this information.



According to Newton's laws

$$F - f = 0$$

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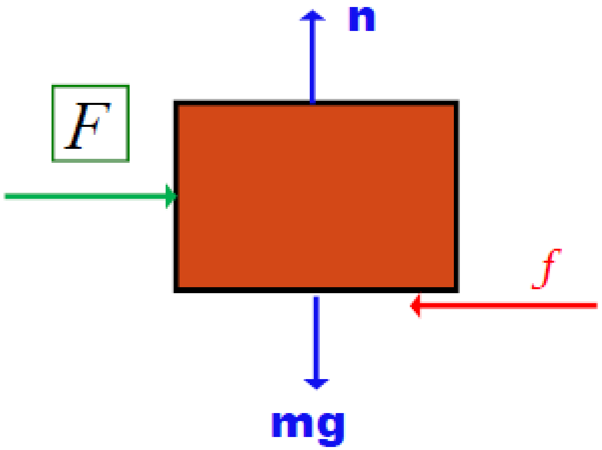


When block is static

$$F - f_s = 0$$

$$\mu_s n = F \qquad \therefore f_s = \mu_s \text{ n}$$ Max. static friction

$$\mu_s = \frac{F}{mg} = \frac{75}{25(9.8)} = 0.30$$

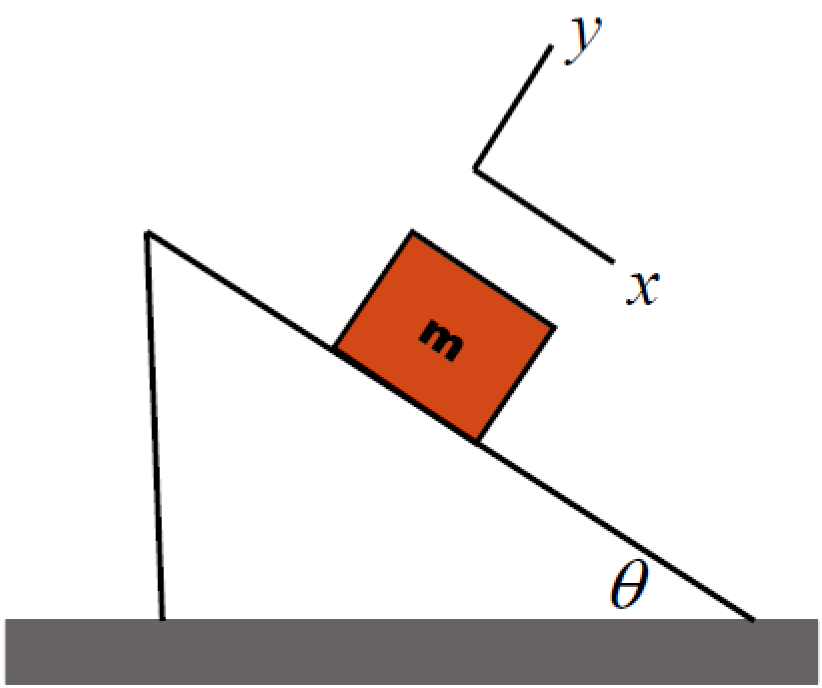
When block is moving

$$F - f_k = 0$$

$$\mu_k n = F$$

$$\mu_k = \frac{F}{mg} = \frac{60}{25(9.8)} = 0.24$$

Suppose a block is placed on a rough surface inclined relative to the horizontal, as shown in Figure. The incline angle is increased until the block starts to move. Show that by measuring the critical angle θ_c *at which this* slipping just occurs, we can obtain μ_s .



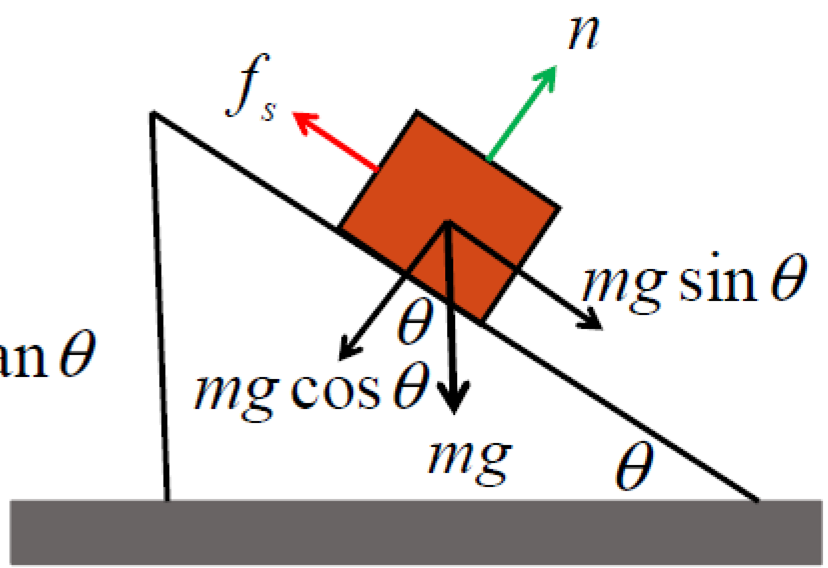
When block is not moving

$$mg\sin\theta - f_s = 0$$

$$n - mg\cos\theta = 0$$

So

$$f_s = mg\sin\theta = \frac{n}{\cos\theta}\sin\theta = n\tan\theta$$



Now

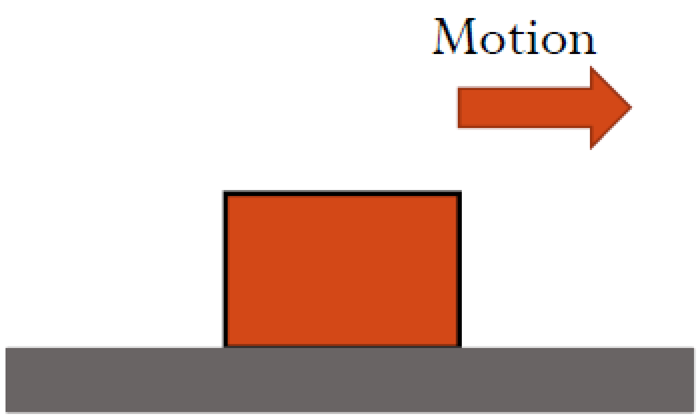
$$\theta = \theta_c \Rightarrow f_s = f_{s\max} = \mu_s n$$

So

$$\mu_s n = n\tan\theta_c$$

$$\boxed{\mu_s = \tan\theta_c}$$

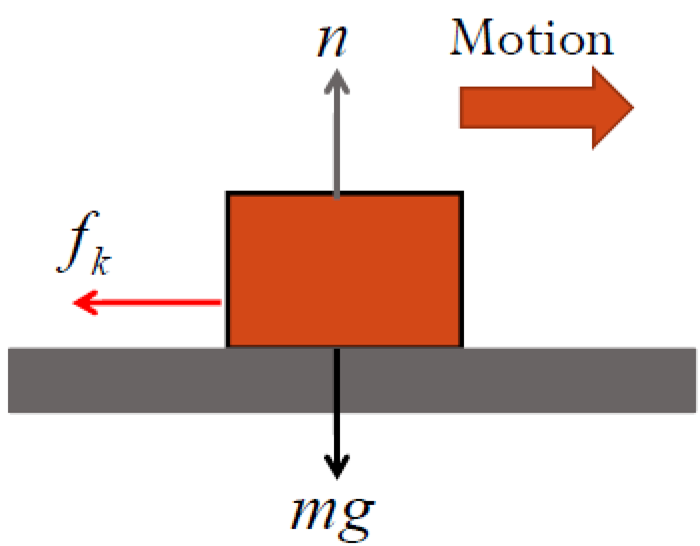
A block on a frozen pond is given an initial speed of 20.0 m/s. If the block always remains on the ice and slides 115 m before coming to rest, determine the coefficient of kinetic friction between the block and ice. (Assume that the friction force is constant, which will result in a constant horizontal acceleration.



According to Newton's Law

$$ma_x = -f_k$$

$$n - mg = 0$$



So horizontal acceleration will be

$$ma_x = -\mu_k n = -\mu_k mg$$

$$a_x = -\mu_k g$$

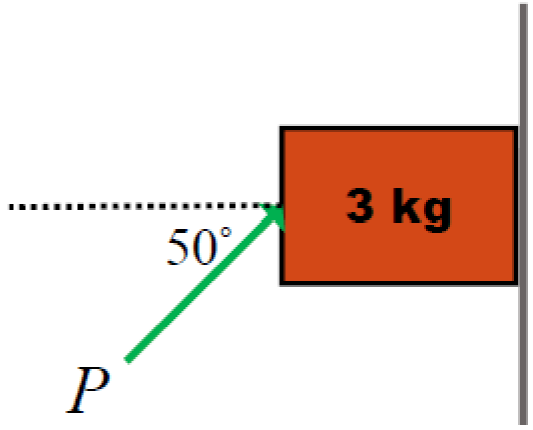
As acceleration is constant, we can use

$$2ax = v_{xf}^2 - v_{xi}^2$$

$$-2\mu_k gx = 0 - v_{xi}^2$$

$$\mu_k = \frac{v_{xi}^2}{2gx} = \frac{(20)^2}{2(9.8)(115)} = 0.11$$

A block of mass 3.00 kg is pushed up against a wall by a force P that makes a 50.0° angle with the horizontal as shown in Figure. The coefficient of static friction between the block and the wall is 0.250. Determine the possible values for the magnitude of P that allow the block to remain stationary.



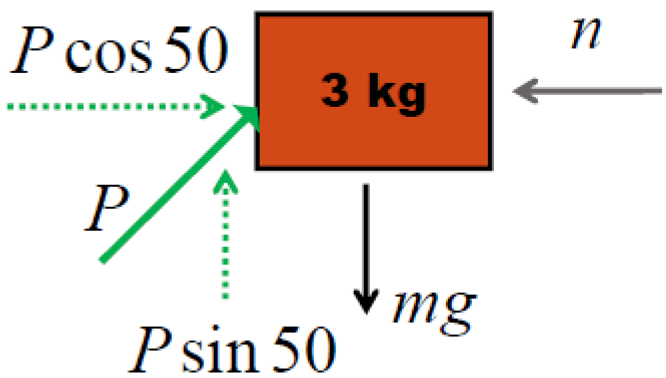
According to Newton's Law

$$\sum F_x = P\cos 50 - n = 0$$

and

$$f_{s\max} = \mu_s \text{ n} = \mu_s P\cos 50$$

$$f_{s\max} = 0.25P\cos 50 = 0.16P$$



There are two cases:

(I) Applied force and friction are such that they stop upward motion.

(II) Applied force and friction are such that they stop downward motion.

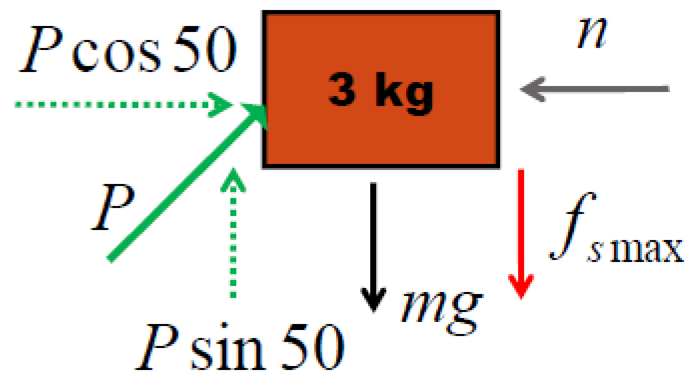
Applied force and friction are such that they stop upward motion.

According to Newton's Law

$$\sum F_y = P\sin 50 - f_{s\max} - mg = 0$$

$$P\sin 50 - 0.16P - (3)(9.8) = 0$$

$$P = 48.6N$$



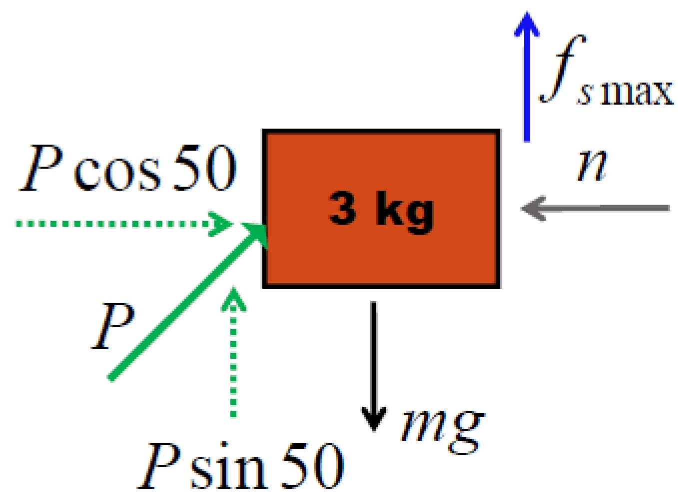
Applied force and friction are such that they stop downward motion.

According to Newton's Law

$$\sum F_y = P\sin 50 + f_{s\max} - mg = 0$$

$$P\sin 50 + 0.16P - (3)(9.8) = 0$$

$$P = 31.7N$$



So the block will remain stationary if **31.7N < P < 48.6N.**

Summary

- The force that counteracts applied force and keeps the object from moving is called the force of static friction f_s .
- The friction force for an object in motion is called force of kinetic friction f_k.
- Experimentally, we find that, to a good approximation, both f_s and f_k are proportional to the magnitude of the normal force.

$$f_{s\,\max} = \mu\, \mathrm{n}$$

$f_{s\,\max}$ is maximum force of friction.

$$\mu_k < \mu_s$$

$$f_s \le \mu_s\, \mathrm{n}$$

$$f_k = \mu_k\, \mathrm{n}$$