# Forces of Nature

# Fundamental Forces

Gravitational Forces

Electromagnetic Forces

Weak Nuclear Forces

Strong Nuclear Forces

- Electrostatic force on two electrons is $10^{36}$ larger the gravitational force.
- Strong forces are nucleonic forces that is responsible for the stability of the nuclei. The magnitude is very large and does not decay as inverse square of the distance. It is a short range force.
- In large atoms weak forces play a key role in phenomenon like radioactivity. It is about $10^{25}$ stronger than the gravitation force, but $10^{11}$ weaker than the electromagnetic force.

**A unified theory for the common origin of all the forces is sought.**

# Everyday forces:

# Contact Forces

# Contact forces

## Force arises from interaction between two bodies.

By contact forces we mean the forces which are transmitted between bodies by short-range atomic or molecular interactions.

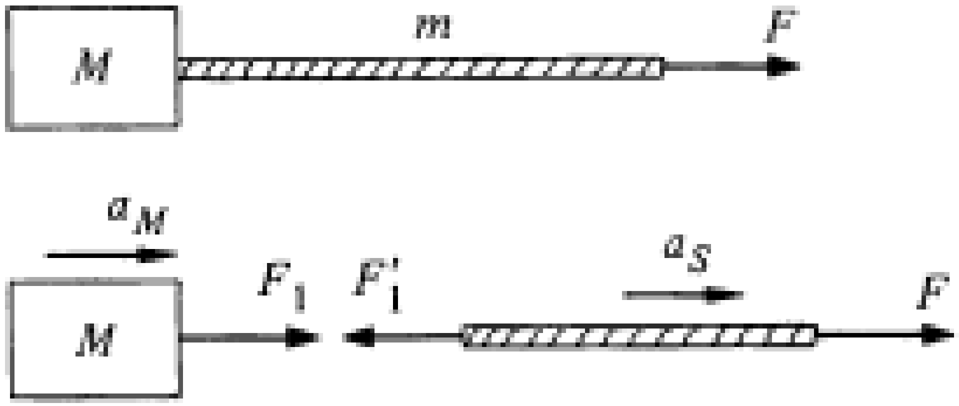
Examples: push, pull, tension of a string, normal force, the force of friction, etc.

The origin of these forces can be explained in terms of the fundamental properties of matter. However, our approach will emphasize the properties of these forces and the techniques for dealing with them in physical problems, not worrying about their microscopic origins.

# Tension in a string: Most common example

A string consists of long chains of atoms. When a string is pulled, we say it is under tension. The long chains of molecules are stretched, and inter-atomic forces between atoms in the molecules prevent the molecules from breaking apart. To illustrate the behaviour of strings under tension:

Consider a block of mass $M$ pulled by a string of mass $m$. A force $F$ is applied to the string. What is the force that the string "transmits" to the block?




$$F_1 = M a_M$$

$$F - F_1' = m a_S.$$

String is inextensible: $a_S = a_M$

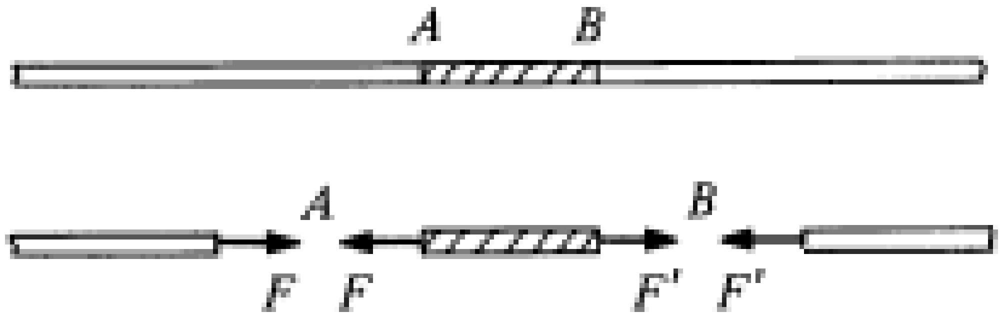
By Newton's third law: $F_1 = F_1'$

$$a = \frac{F}{M+m},$$

$$F_1 = F_1' = \frac{M}{M+m} F.$$

The force on the block is less than $F$. The string does not transmit the full applied force. If the mass of the string is negligible compared with the block, $F_1 = F$ to good approximation.

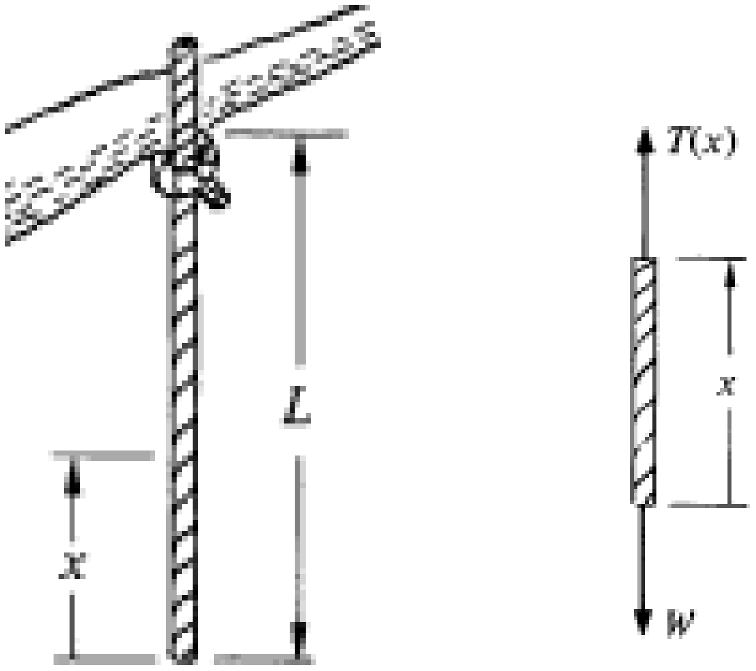
A string is composed of short sections interacting by contact forces. Each section pulls the sections to either side of it, and by Newton's third law, it is pulled by the adjacent sections. The magnitude of the force acting between adjacent sections is called **Tension**. **There is no direction associated with tension.** In the sketch, the tension at *A* is *F* and the tension at *B* is *F*'.




- Although a string may be under considerable tension, if the tension is uniform, the net string force on each small section is zero and the section remains at rest unless external forces act on it.
- If there are external forces on the section, or if the string is accelerating, the tension generally varies along the string.

# Dangling rope

A uniform rope of mass *M* and length *L* hangs from the limb of a tree. Find the tension a distance x from the bottom.



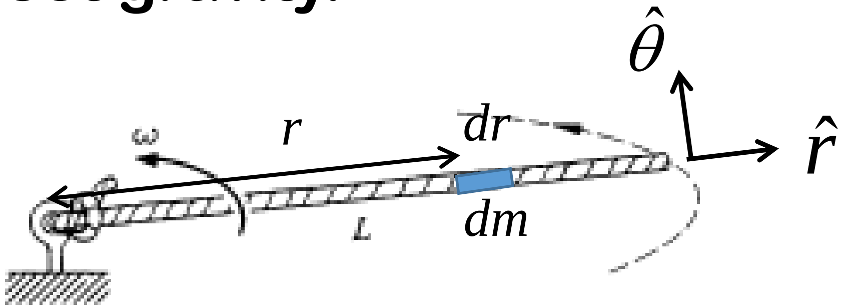

$$W = Mg(x/L).$$

$$T(x) = \frac{Mg}{L}x.$$

At the bottom of the rope the tension is zero, while at the top the tension equals the total weight of the rope *Mg*.

# Whirling rope

**A uniform rope of mass *M* and length *L* is pivoted at one end and whirls with uniform angular velocity ω. What is the tension in the rope at distance *r* from the pivot? Neglect gravity.**



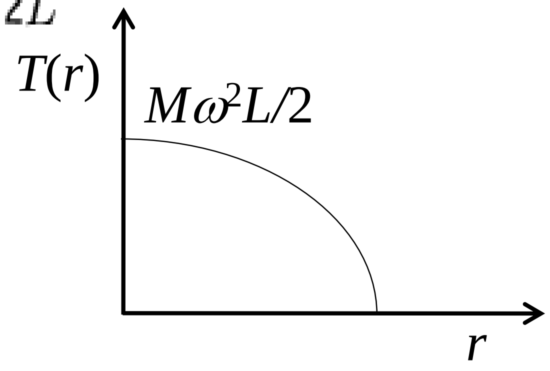

$$\vec{a} = \left(\ddot{r} - r\dot{\theta}^2\right)\hat{r} + \left(r\ddot{\theta} + 2\dot{r}\dot{\theta}\right)\hat{\theta};$$

$$\ddot{r} = \dot{r} = 0,\ \ddot{\theta} = 0 \qquad \vec{a} = -r\omega^2\hat{r}$$

$$dT(r) = -r\omega^2 dm; \quad dm = \rho dr = \frac{M}{L}dr$$

$$dT = -\frac{M\omega^2}{L} r\,dr \quad \int_{T_0}^{T(r)} dT = -\int_0^r \frac{M\omega^2}{L} r\,dr, \quad T(r) - T_0 = -\frac{M\omega^2}{L}\frac{r^2}{2}$$

$$T(r) = T_0 - \frac{M\omega^2}{2L} r^2.$$



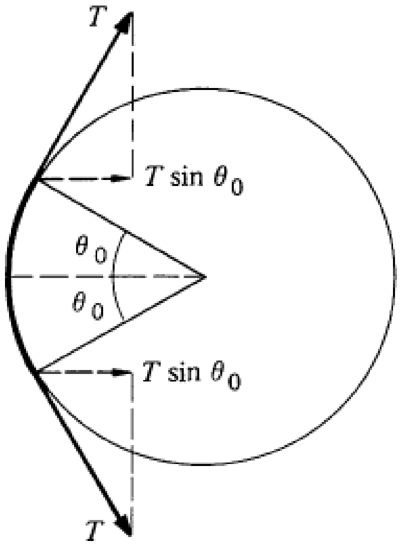

$$T(L) = 0 = T_0 - \tfrac{1}{2}M\omega^2 L. \qquad T_0 = \tfrac{1}{2}M\omega^2 L,$$

$$T(r) = \frac{M\omega^2}{2L}(L^2 - r^2).$$

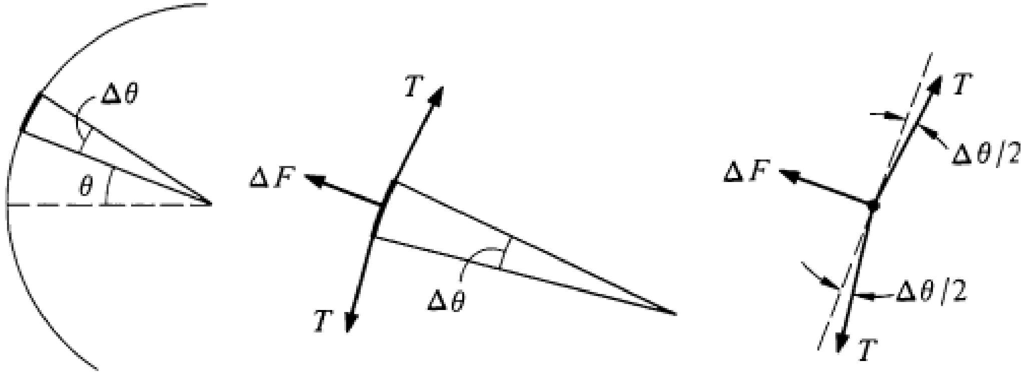
# Pulleys

**When a pulley is used to change the direction of a rope, there is a reaction force on the pulley. The force on the pulley depends on tension and the angle through which the rope is rotated.**

A string with constant tension $T$ is deflected through angle $2\theta_0$ by a smooth fixed pulley. What is the force on the pulley?



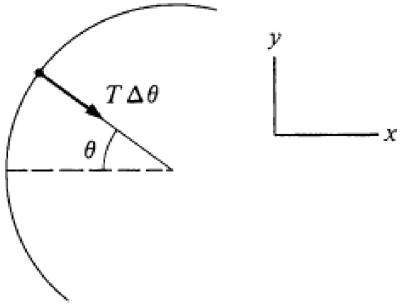

$2T \sin\theta_0$




$$\Delta F - 2T\sin\frac{\Delta\theta}{2} = 0$$

For small $\Delta\theta$, $\sin(\Delta\theta/2) \approx \Delta\theta/2$ and $\Delta F = 2T\dfrac{\Delta\theta}{2} = T\Delta\theta$.

Thus the element exerts an inward radial force of magnitude $T\Delta\theta$ on the pulley.




$$\int_{-\theta_0}^{\theta_0} T\cos\theta\, d\theta = 2T\sin\theta_0.$$

# Friction

- **Mostly encounter two kinds of friction:**

**(i) Sliding friction – Comes into play when two bodies slide on one another. All surfaces are rough at the atomic level.**

**(ii) Fluid/Air friction – At very small velocities, air friction is absent. Usually at moderate velocities, it is proportional to velocities (such as a ball moving through viscous fluids). At very large velocities (such as an aeroplane where the air swirls around as the plane moves), friction may be proportional to square of velocity or even higher powers.**

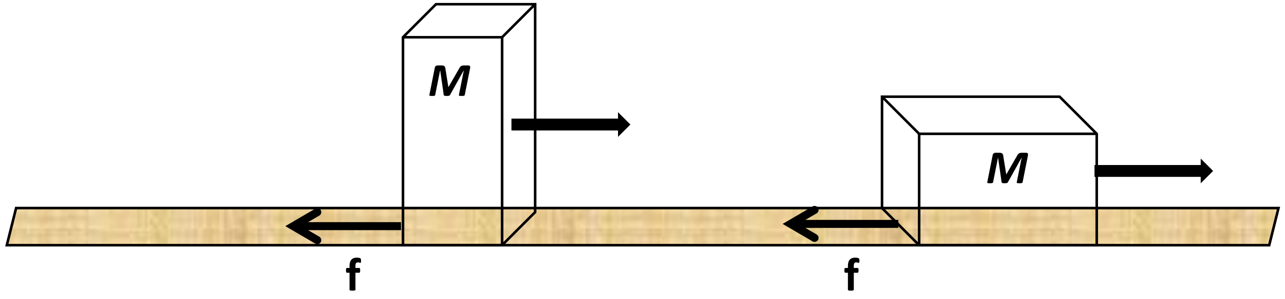
# Sliding Friction

- Friction arises when the surface of one body moves, or tries to move, along the surface of a second body.

- The maximum value of the friction is $f_{friction} = \mu N$
where $N$ is the normal force and $\mu$ is the coefficient of friction.

- When a body slides across a surface, the friction force is directed opposite to the instantaneous velocity and has magnitude $\mu N$. The force of sliding friction is slightly less than the force of static friction, but for the most part we shall neglect this effect.

- For two given surfaces, the force of sliding friction is independent of the area of contact.



# Important features of Friction

- Friction is independent of the area of contact because the actual area of contact on an atomic scale is a minute fraction of the total surface area.

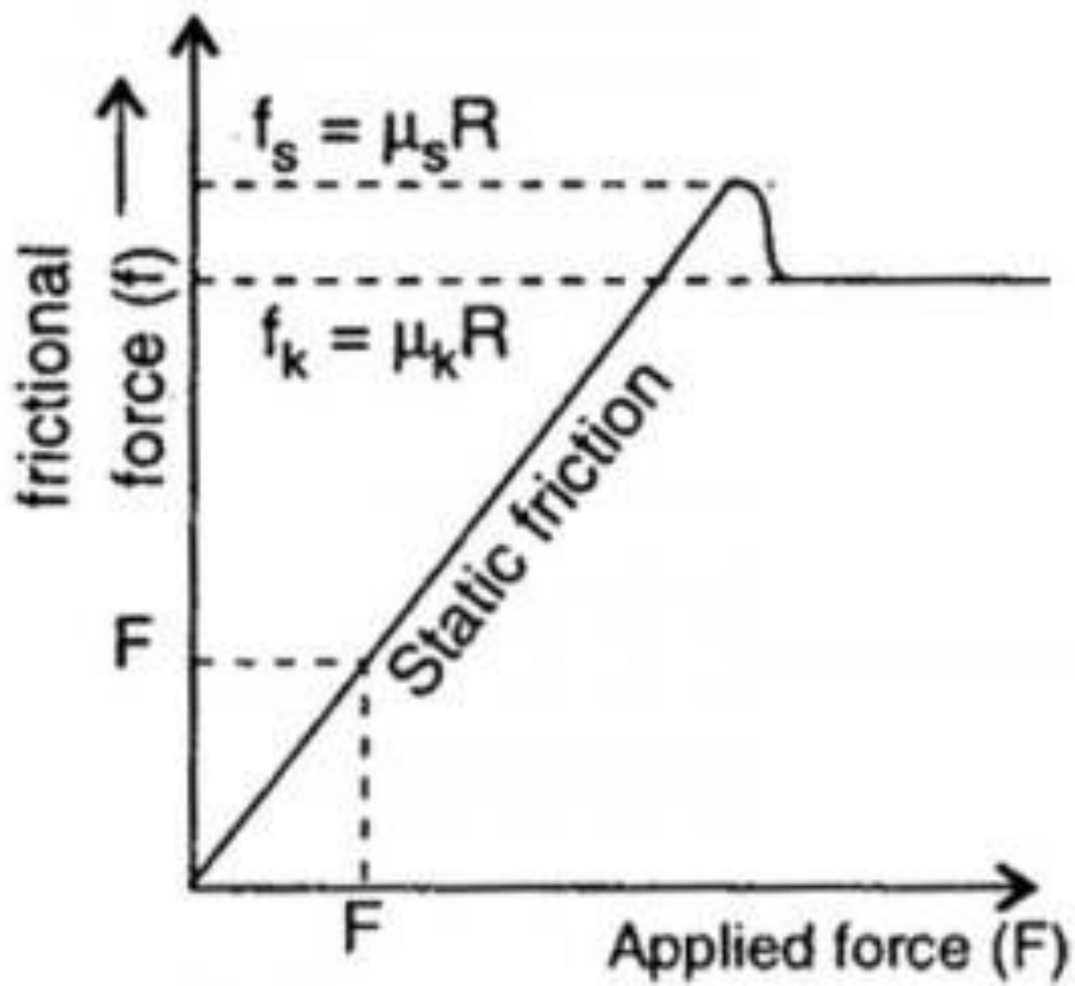
- Friction occurs because of the interatomic forces at these minute regions of atomic contact.

- Non rigid bodies, like automobile tires, are more complicated. A wide tire is generally better than a narrow one for good acceleration and braking.

- Frictional force is also independent of relative velocity between two surfaces.

- This is approximately true for a wide range of low speeds, as the speed increases and air friction come into play, it is found that friction not only depends on the speed, but upon the square and sometimes higher powers of the speed.

# Applied force vs Frictional force



# Laws of Friction vs Newton's laws

- Two laws of friction:

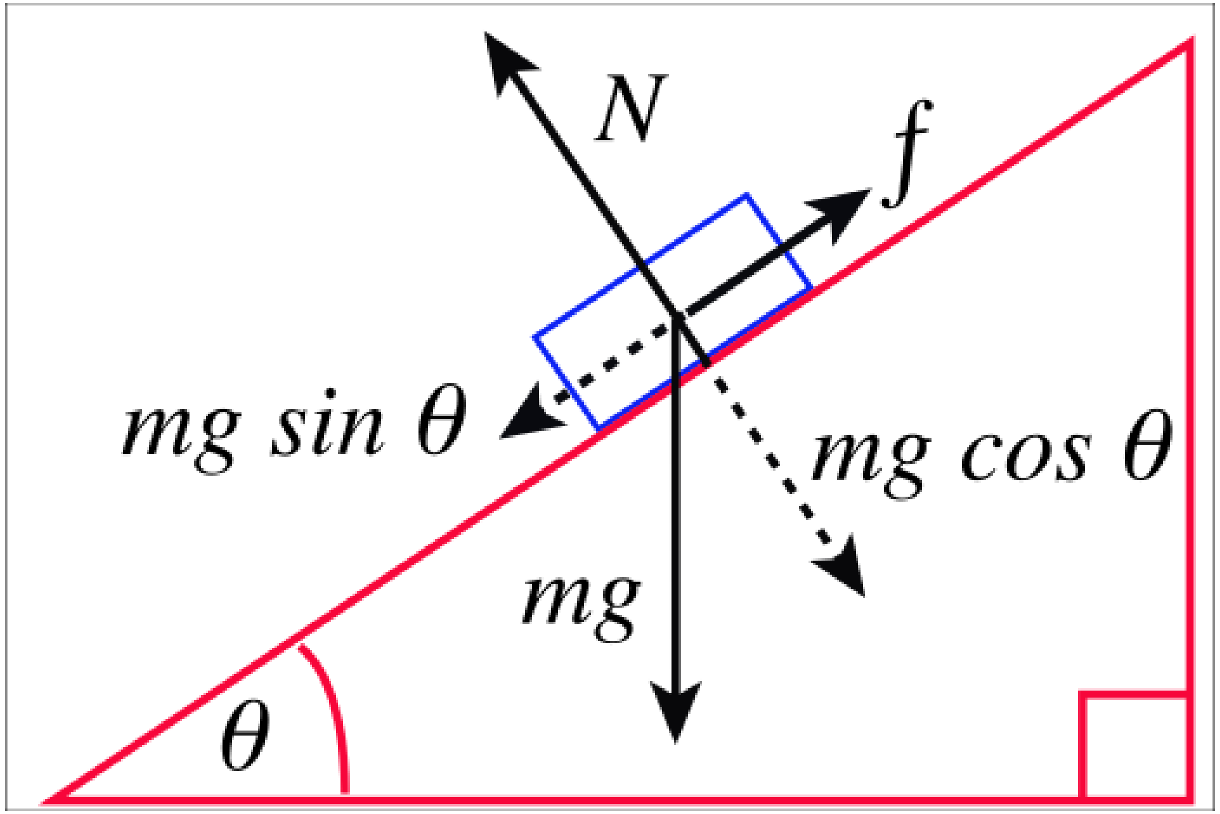
$$F = \mu N \quad \text{(for sliding)}$$

$$F = cv^{\alpha} \quad \text{(for fluid friction)}; \ \alpha = 1,2,\ldots$$

Distinguish it with $F = ma$ !!

**Newton's laws are real laws, while laws of friction are empirical laws.**

# How to experimentally determine friction or test F = μN?




At the verge of sliding

$$mg\ sin\theta = \mu N = \mu mg\ cos\theta$$

$$\mu = \tan\theta$$

An object will start to slude at a given inclination. If the same block is loaded by providing extra weight, it will still be sliding at the given angle. Coefficient of friction is constant for a given angle.

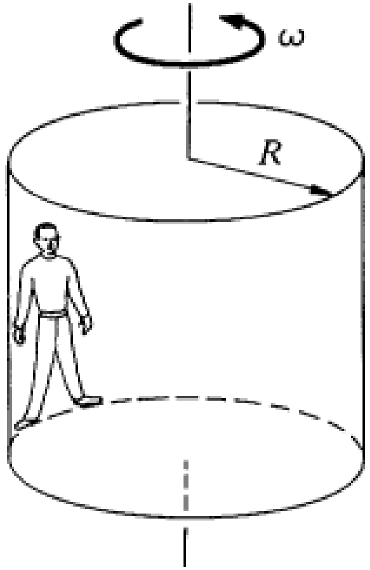
In fact if this experiment is performed by continuously varying the angle, then at the correct angle, the block begins to slide, **but not steadily.** Thus μ being constant Is only roughly true.

# Some typical values of coefficients of friction

- Steel on steel m$_s$ *= 0.58*
- Masonry on rock m$_s$ *= 0.6-0.7*
- Masonry on clay m$_s$ *= 0.30*
- Wood on brick m$_s$ *= 0.6*
- Rubber sliding on bitumen at 100m/min m*= 1.07*

# The spinning terror

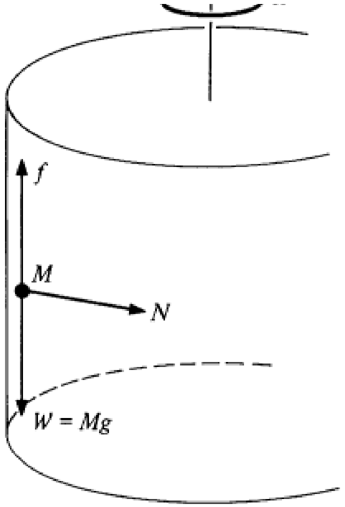
The Spinning Terror is an amusement park ride—a large vertical drum which spins so fast that everyone inside stays pinned against the wall when the floor drops away. What is the minimum steady angular velocity $\omega$ which allows the floor to be dropped away safely?




$$N = MR\omega^2.$$

By the law of static friction,

$$f \le \mu N = \mu M R \omega^2.$$

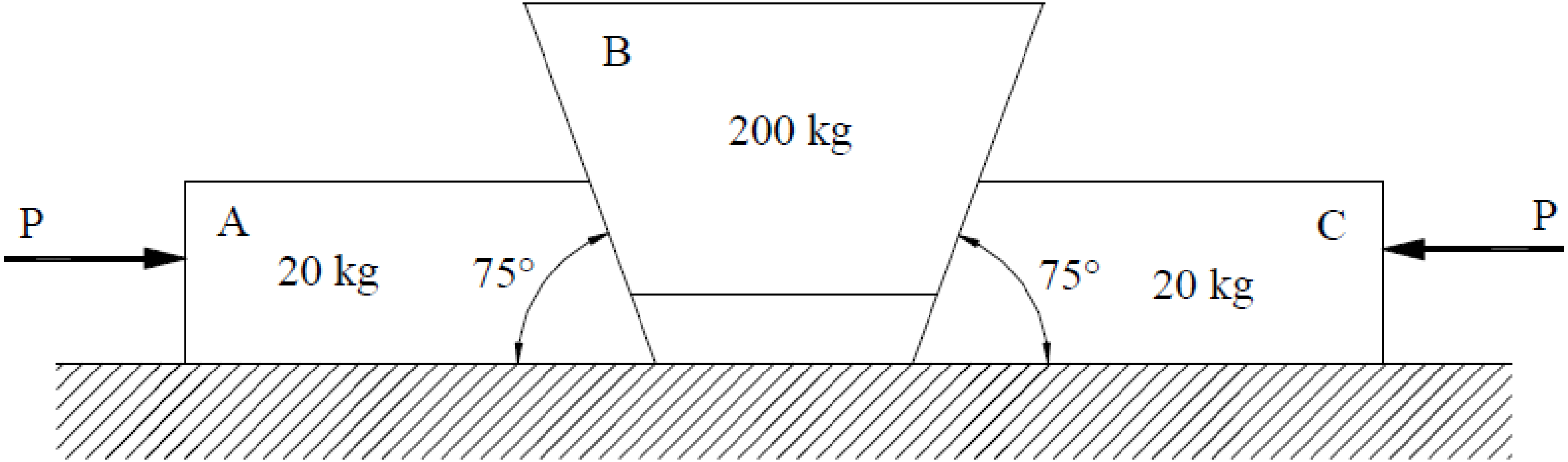



Since we require $M$ to be in vertical equilibrium, $f = Mg,$

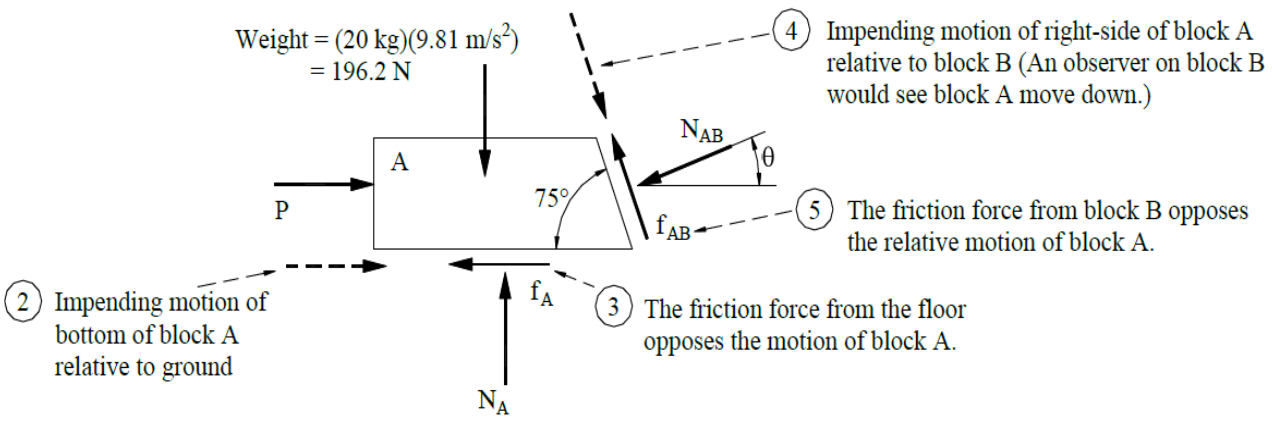
**Therefore,** $Mg \le \mu M R \omega^2$ or $\omega^2 \ge \frac{g}{\mu R}.$ or $\omega_{\min} = \sqrt{\frac{g}{\mu R}}.$

# The blocks and friction

. If the coefficient of static friction for all surfaces of contact is 0.25, determine the smallest value of the forces P that will move wedge B upward.



(1) Free-body diagram of block A




(6) Equations of equilibrium

$\xrightarrow{+} \sum F_x = 0$: $P - f_A - f_{AB}\cos 75° - N_{AB}\cos\theta = 0$ (1)

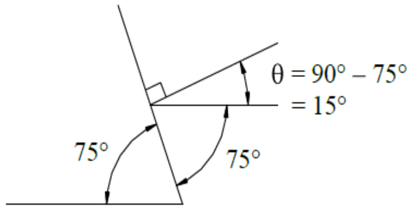
$+\uparrow \sum F_y = 0$: $N_A - 196.2\text{ N} + f_{AB}\sin 75° - N_{AB}\sin\theta = 0$ (2)

Slip impends so,

$f_A = f_{A\text{-max}} \equiv \mu N_A = 0.25 N_A$ (3)

$f_{AB} = f_{AB\text{-max}} \equiv \mu N_{AB} = 0.25 N_{AB}$ (4)

(7) Geometry




(11) Solving Eqs. 1– 4 and 6 simultaneously, with θ = 75°, gives

$f_A = 294\text{ N} = 0.294\text{ kN}$

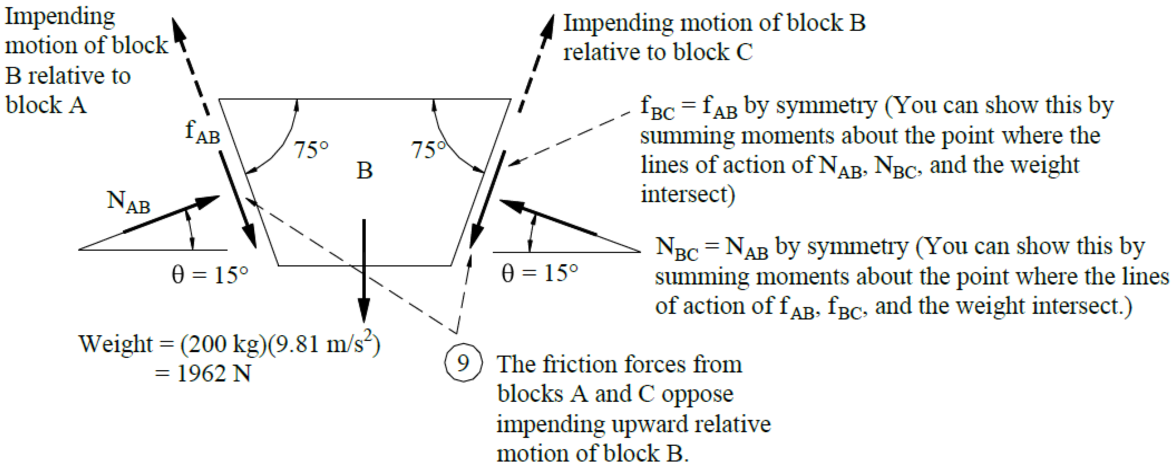
$N_A = 1\,180\text{ N} = 1.18\text{ kN}$

$f_{AB} = 14\,150\text{ N} = 14.15\text{ kN}$

$N_{AB} = 56\,600\text{ N} = 56.6\text{ kN}$

$P = 58\,600\text{ N} = 58.6\text{ kN}$ ←Ans.

(8) Free-body diagram of block B




(10) Equations of equilibrium

$\xrightarrow{+} \sum F_x = 0$: $N_{AB}\cos 15° - N_{AB}\cos 15° + f_{AB}\cos 75° - f_{AB}\cos 75° = 0$ (5)

(Note that this equation reduces to 0 = 0. This happens because we have assumed symmetry to conclude that $f_{BC} = f_{AB}$ and $N_{BC} = N_{AB}$.)

$+\uparrow \sum F_y = 0$: $N_{AB}\sin 15° + N_{AB}\sin 15° - f_{AB}\sin 75° - f_{AB}\sin 75° - 1962\text{ N} = 0$ (6)