

Lecture 6: Friction

Part 1: Friction Phenomena

Friction is a force which is generated _____ between _____. Its direction is always _____ to that of the motion, or tendency for a motion.

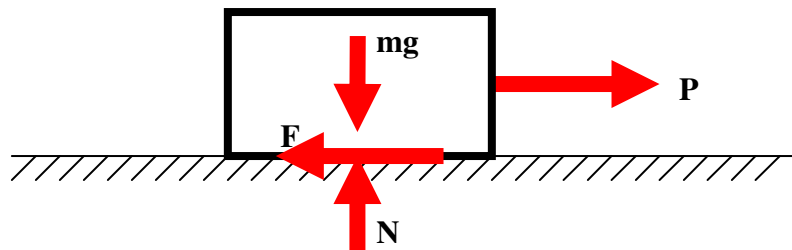


Figure 1

Figure 1 shows a block of mass m being pulled horizontally by a force P . The _____ surface exerts a normal force N to support the weight of the block and a friction force F to resist the motion in the direction of P .

Friction forces exist everywhere in both nature and man made objects, both intentionally or not. Friction can be beneficial, or even essential in certain applications such as _____. On the other hand, some applications such as _____ require minimum friction.

Types of friction

1. _____ (also known as Coulomb friction). It occurs when unlubricated (nonsmooth or rough) surfaces of _____ are in contact under a condition of _____. An example of this type of friction is shown in figure 1. This type of friction will be explained in details in the next section.
2. _____. It occurs when adjacent layers in a moving viscous fluid are moving at different velocities. The shearing action

caused by the relative velocity between the layers account for the fluid friction.

3. _____. It occurs in all solid materials subjected to cyclic loadings. Internal friction is present during deformation and causes a loss of energy.

In this course, we will only concentrate on _____.

Dry Friction

As stated before, dry friction occurs at the contact between two rough surfaces during a sliding motion or under a tendency to slide. The friction force is always tangent to the surface and its direction always opposes the motion or the impending motion.

Mechanism of Dry Friction

Let us consider the block in figure 1 (redrawn in figure 2a). The block is vertical equilibrium as the force N is equal to its weight mg . However, the block may or may not slide horizontally depending on the magnitudes of the force P and the friction F .

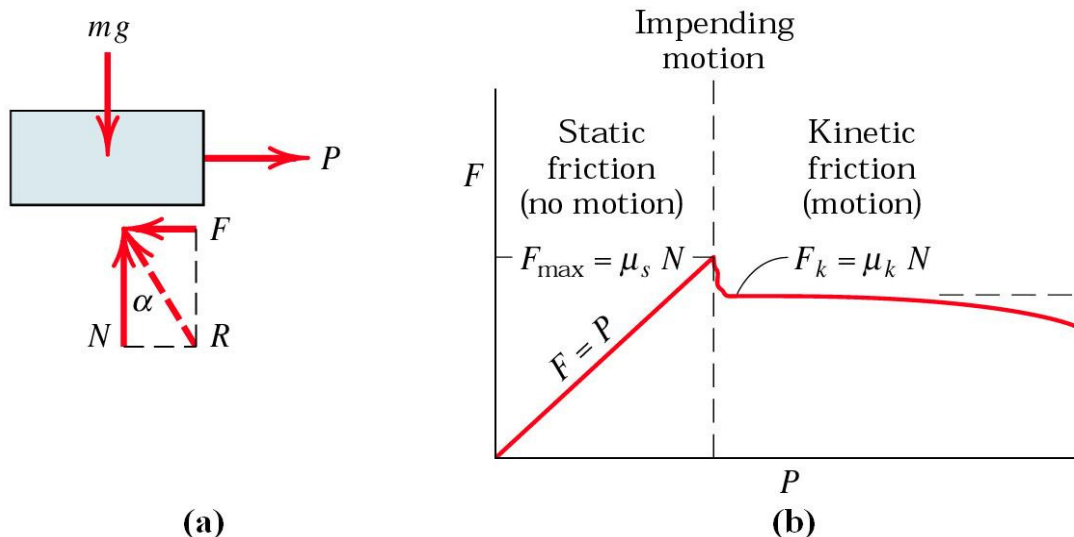


Figure 2

The curve in figure 2b shows us two regions on either side of the vertical dotted line labeled '_____'. These regions correspond to the types of behavior of the block upon the application of force P .

Stationary Block – No motion is present

If the magnitude of the force P is less than that required for the block to move, the system lies in the region to the _____ of the dotted line. In this region, the friction force is called the _____, as _____ in the system.

The main characteristic of this region is the linear relationship _____, which is expected because the forces must be in equilibrium in order for the block to be stationary.

The block will remain stationary as long as the _____, which is defined as

_____ where μ_s is a constant called the _____.

When $P = F_{max}$, the block is said to _____.

Moving Block – Motion is present

After slipping has occurred and the block is now _____, the friction that the block is now experiencing is called the _____. Kinetic friction is somewhat less than the maximum static friction force (at the point of impending motion) as shown in figure 2b.

For $P > F_{max}$, the kinetic friction F_k is also proportional to the normal force, as shown by the relationship

_____ where μ_k is a constant called the _____ and usually _____.

However, as the velocity of the block increases and $P \gg F_{max}$, the kinetic friction decreases quite significantly. This effect is shown in figure 2b.

Friction Angles

The direction of the resultant force R in figure 2a makes an angle α with the vertical component. The magnitude of this angle can be computed via the relationship

_____.

When the friction force reaches the _____, the angle reaches a _____, where

_____.

The angle ϕ_s is called the _____.

Similarly, the *angle of* _____ is given by

_____.

Coefficients of friction

Given below is a table of coefficients of friction between typical types of surfaces found in engineering applications. Note that these only represent typical values under normal working conditions. They may vary depending on the exact nature of the contact surfaces and working environment.

TYPICAL VALUES OF
COEFFICIENT OF FRICTION

CONTACTING SURFACES	STATIC, μ_s	KINETIC, μ_k
Steel on steel (dry)	0.6	0.4
Steel on steel (greasy)	0.1	0.05
Teflon on steel	0.04	0.04
Brass on steel (dry)	0.5	0.4
Brake lining on cast iron	0.4	0.3
Rubber tyres on smooth pavement (dry)	0.9	0.8
Wire rope on iron pulley (dry)	0.2	0.15
Hemp rope on metal	0.3	0.2
Metal on ice		0.02

Part 2: Engineering Applications of Friction

Friction forces appear extensively in engineering applications. Here we will investigate the action of these forces in the following systems

- Wedges
- Screws
- Journal bearings
- Thrust bearings (Disk friction)
- Flexible belts and cables

Wedges

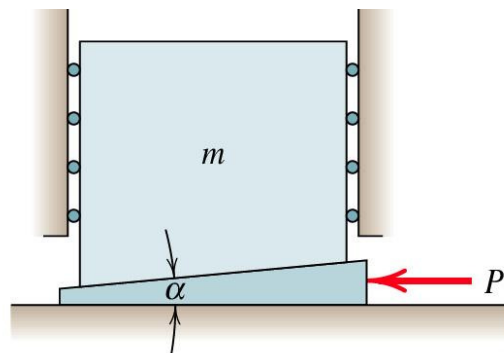


Figure 1

A wedge is a very simple tool used in mechanical applications and also found in everyday life, such as a door stopper. It is commonly used to _____ or used to _____ (see illustration in figure 1).

We will analyse the forces in the example system shown in figure 1.

Force Analysis

The wedge utilises the friction forces between itself and the object it is in contact with and also with the ground (or wall) it is resting upon.

A _____ is one whose friction forces acting on its surfaces are enough to keep the wedge and other objects it is in contact with, in _____.

Consider the force P in figure 1. If its magnitude is large enough, it will move the wedge to the left and, as a result, the block of mass m will be pushed upwards.

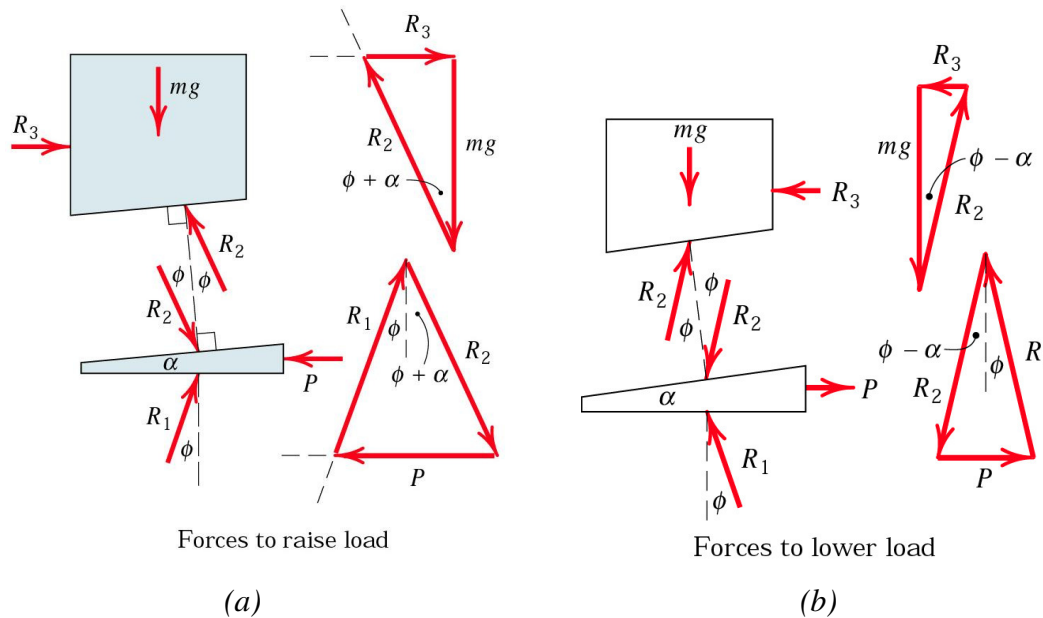


Figure 2

Now let us consider the free body diagrams of both blocks in such configuration as shown in figure 2a.

Wedge: R_1 is the resultant force exerted by the ground on the wedge. It is a combination of friction and a vertical component which supports the weight of the block. The reaction is inclined at an angle ϕ where $\tan \phi = \mu$.

R_2 is the resultant force exerted by the block on the wedge. It consists of the friction force between the block and the wedge, and the vertical component caused by the block's weight. This reaction is inclined at an angle ϕ to the normal to the wedge surface.

Block: The force R_2 that the block experiences is equal and opposite to the force R_2 acting on the wedge. A reaction R_3 must be present in order to keep the block in horizontal equilibrium. Finally, the weight of the block acts through its centre of gravity.

Similarly, if the force P reverses its direction, the impending motion will result in the block being lowered. The free body diagrams of the block and the wedge are shown in figure 2b.

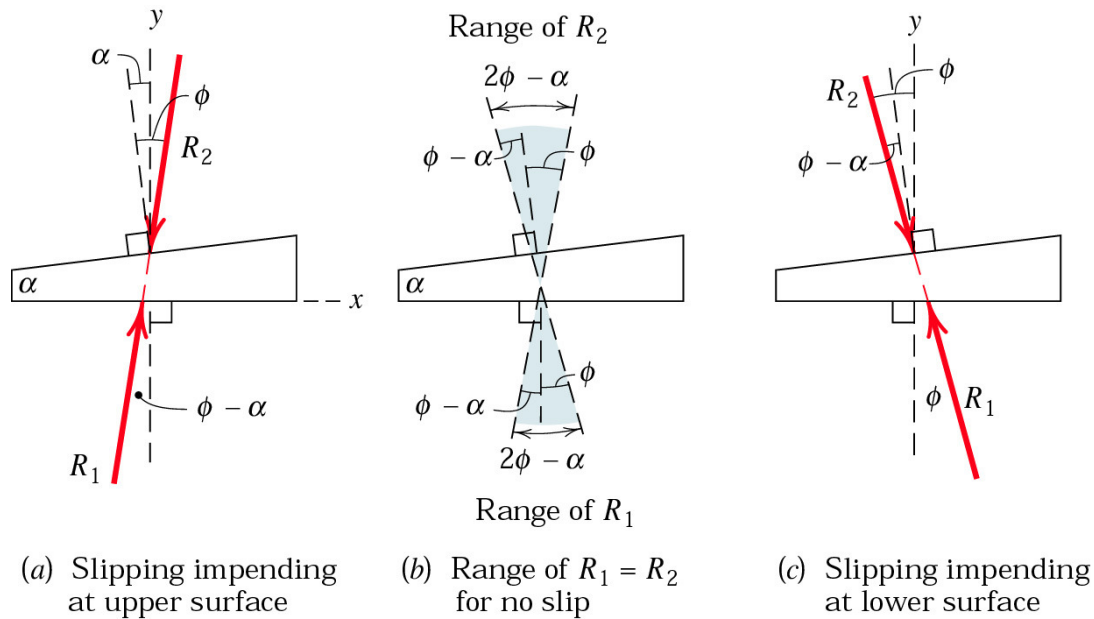


Figure 3

This system has three possible scenarios.

1. The block is _____. This is possible if the force P is _____ enough to overcome the friction forces and the horizontal component of the weight mg . See figure 3a.
2. The block is _____. This is possible if (1) the force P is _____ than the maximum possible combined horizontal force resisting the motion or (2) the force P is _____ and the friction force is able to _____ the impending motion of the block due to its own weight. See figure 3b.
3. The block is _____. This is possible if (1) the direction of force P is _____ and the maximum friction force is _____ to resist the motion or (2) the force P is _____ and the coefficient of friction between the surfaces is so _____ that slipping occurs. See figure 3c.

Screws

Screws are used to _____ or _____.

They function by employing the _____.

Note that all screws analysed here are confined to those with square thread.

Force Analysis

In the following analysis, we will use the screw model shown in figure 4a. The length L represents the _____.

The force W may also represent a load, hence the entire system can be thought of as a jack which can lower or raise the load whose weight is W .

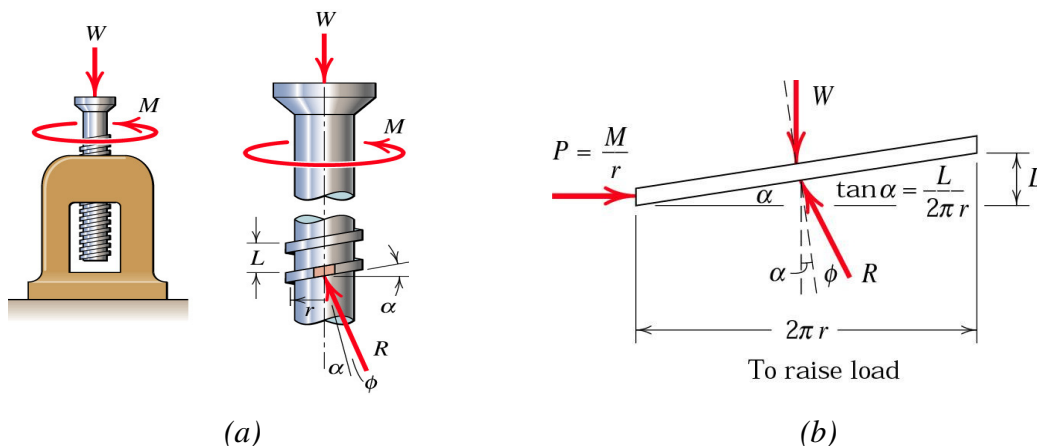


Figure 4

Raising the weight

The free body diagram shown in figure 4b is a _____ of the screw thread whose length is of one revolution; hence its height is represented by the lead L . The equilibrium equations of the system can be simplified to give the relationship

Lowering the weight

Using a similar approach, the free body diagrams of the straightened portion of the screw thread with impending downward motion are shown in figure 5.

In the case of figure 5a, the friction exerted on the screw is enough to keep the system _____ even if the force P _____,

i.e. _____. Mathematically, this will happen if _____. The equilibrium equation of this system is given by _____

In the case of figure 5b, the friction is so _____ that the load W will push the screw downward if force P is absent. The moment required to prevent unwinding is given by _____

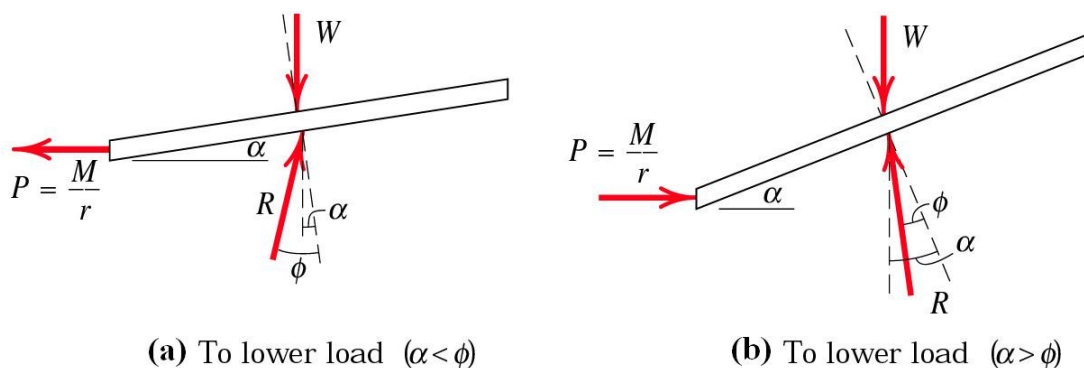


Figure 5

Journal Bearings

A journal bearing gives _____ support to a shaft. The cross section of the bearing in figure 6 is supporting a rotating shaft within its ring. The contact between the shaft and the bearing is assumed to be partially lubricated and the theory of dry friction can be applied here.

Force Analysis

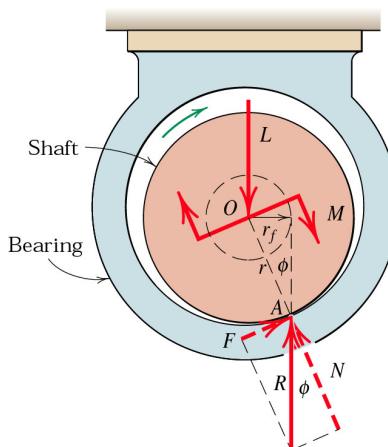


Figure 6

The shaft is rotating in the anticlockwise direction and the forces and moments acting on it are shown. The rotating shaft seems to have climbed up the bearing slightly, so that the reaction force is now not collinear with the weight vector. Thus, taking the _____ gives

_____.

Since the friction angle ϕ is assumed small, it can be approximated that _____ without error. Recall that the coefficient of friction is defined $\mu = \tan \phi$, the equilibrium equation now becomes

_____.

Thrust Bearings (Disk Friction)

A good example of a disk friction is the use of _____ in vehicles. This application of friction forces involves a rotating surface about an axis and the torque required to start a rotation.

Force Analysis

Let us consider a pair of circular discs of radius R mounted on collinear axes as shown in figure 7. An axial force P brings the two discs in contact with each other while moments M cause the discs to rotate in opposing directions.

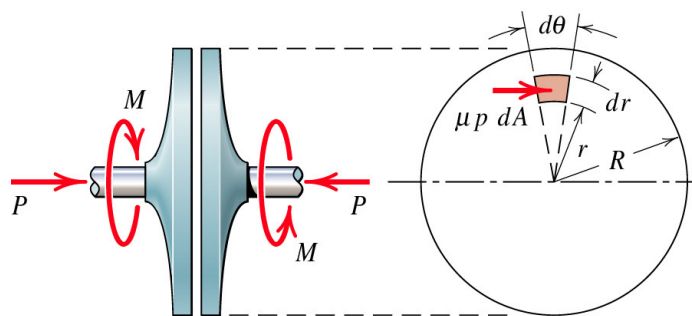


Figure 7

The impending motion is a rotation about the axle, hence the friction _____.

Let us consider the circular cross section area shown on the right of figure 7.

The moment about the centre of the disc caused by the friction force on the elemental area dA is given by

Integrating the above expression over the entire area of the disc to obtain the total frictional moment to obtain

Let us assume further that the disc we are analysing is new and its surface is _____ so that the pressure P is _____.
i.e. the pressure per unit area is _____. Finally, in the case of circular discs here, we can include the limits of integration to obtain

$$M = \frac{2}{3} \mu P R$$

Flexible Belts and Cables

The belt drives, band brakes and hoisting rigs all make use of friction forces between the _____.

Force Analysis

Figure 8 shows a drum and a belt under tension over it. The drum can rotate about its centre. The tension _____, hence it generates a moment about the centre of the drum which is counteracted by the moment M to prevent any motion.

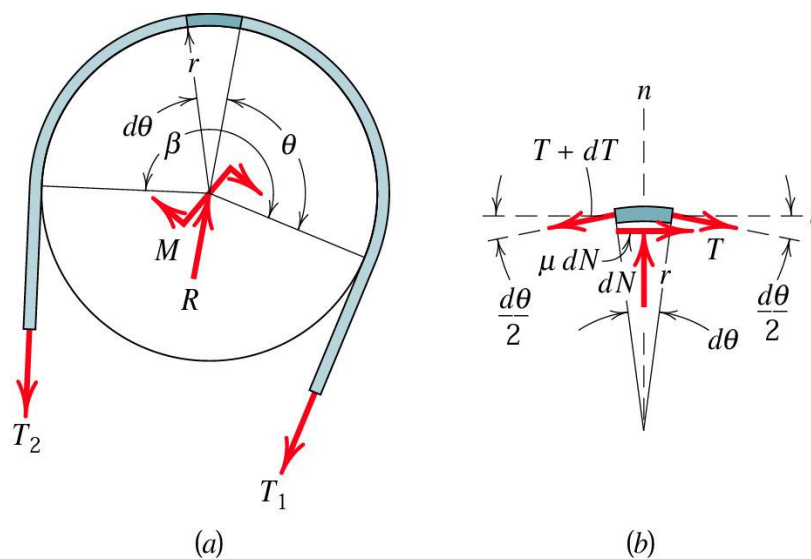


Figure 8

Let us consider only a small element of the belt whose free body diagram is shown in figure 8b. This element is in equilibrium, therefore by resolving the forces in the

_____ we obtain

Note that cosine of a small angle is _____,
i.e. $\cos d\theta \approx 1$. Similarly, the equilibrium equation in the _____
gives

Here we use an assumption that sine of a small angle is equal to the angle itself,
i.e. $\sin d\theta \approx d\theta$, and the products of two differentials are considered small and can be neglected.

Combining the two equilibrium equations to obtain

$$\frac{dT}{T} = \mu d\theta$$

Integrating both sides with the limits shown in figure 8 yields

$$\int_{T_1}^{T_2} \frac{dT}{T} = \int_0^{\beta} \mu d\theta$$

$$\ln \frac{T_2}{T_1} = \mu \beta$$

Rearranging the solution to obtain

where β represents the _____.

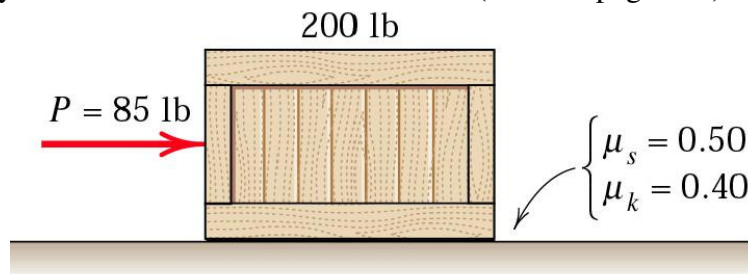
Remember that _____

_____.

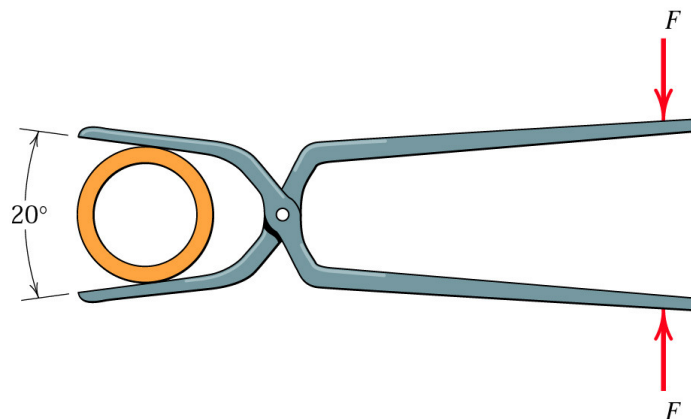
Lecture 6: Exercises

Part 1

- (1) The 700N force is applied to the 100kg block as shown in the figure. The block is originally at rest. Determine the magnitude and direction of the friction force F exerted by the horizontal surface of the block. (Meriam page 338)

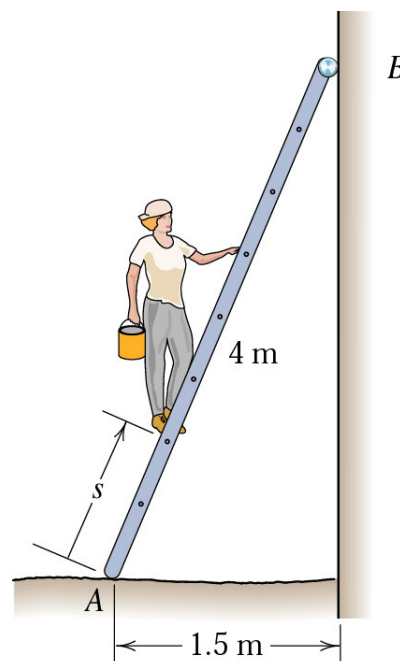


- (2) The tongs are designed to handle steel tubes as shown below. For a 20° jaw opening, find the minimum coefficient of static friction between the jaws and the tube which enables the tongs to grip the tube without slipping. (Meriam page 339)



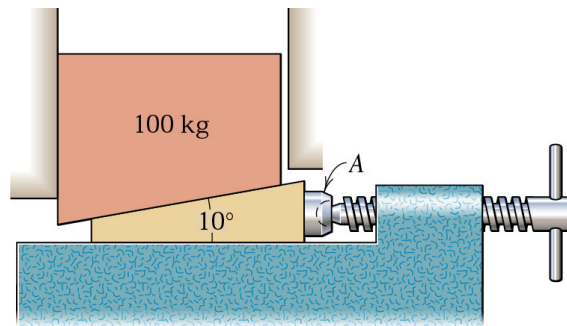
- (3) Determine the distance s to which a 90kg person can safely climb without causing the ladder to slip at the lower end. The top part of the ladder has a smaller roller which rests on the vertical wall and the coefficient of static friction between the ladder and the ground is 0.25. It can be assumed that only the feet of the person are in contact with the ladder. (Meriam page 344)

Hint: Begin with a free body diagram of the ladder.

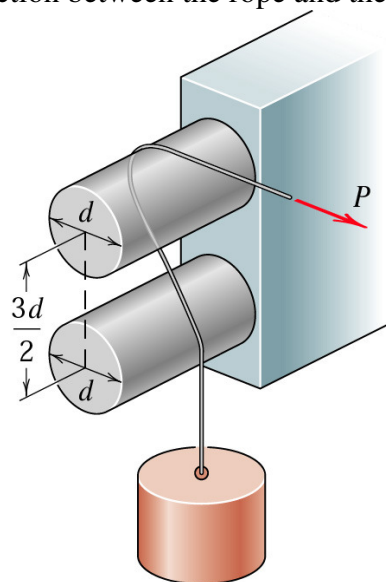


Part 2

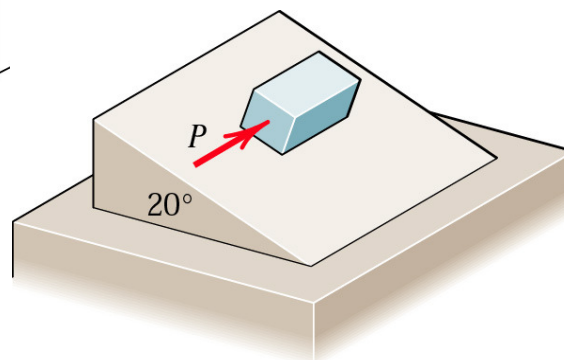
- (1) The vertical position of the 100kg block is adjusted by the screw-activated wedge. Compute the moment M which must be applied to the screw handle in order to raise the block. The screw has a mean diameter of 30mm and advances 10mm for each complete revolution. The coefficient of friction for the screw threads is 0.25, and the coefficient of friction between the wedge and the block is 0.40. (Meriam page 357)



- (2) Starting from equation $M = \int \mu p r dA$, use the same approach as shown in this lecture to determine the frictional moment generated by a ring friction disc. Assume that its surface is new so the pressure is evenly distributed. The inner and outer diameters of the ring disc are given by R_i and R_o , respectively.
- (3) Compute the horizontal force P required to raise the 100kg load. The coefficient of friction between the rope and the fixed bars is 0.40. (Meriam page 373)



100 kg
Question (3)



Question (4)

- (4) The 8kg block is resting on a 20° inclined plane with a coefficient of static friction $\mu_s = 0.50$. Determine the minimum horizontal force P which will cause the block to slip. (Meriam page 380)

