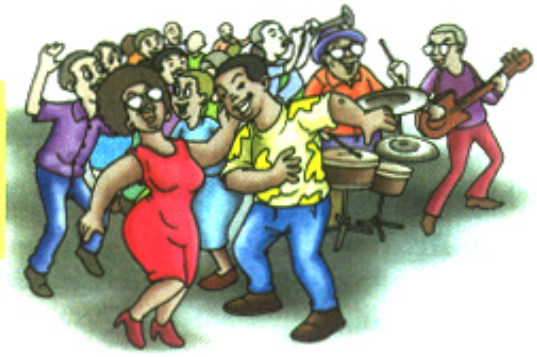
3 FORCE AND MOTION



FORCE

Evidences abound to show that forces exist in nature. From the orbit of the planets round the sun down to that of the electrons around the nucleus, forces are responsible. The expansion of materials when hot, the translation of a body, and the vibration of particles are all caused by forces.

OBJECTIVES

At the end of the lesson, students should be able to:

- state that force makes a given body move;
- identify the force which slows down and finally stops a moving body;
- identify a force resisting the motion between two surfaces in contact and moving relative to each other;
- state the methods of reducing friction.

What is a force?

To move a box across a room, we either **push** or **pull** it. Pushing or pulling moves the box and work is done. Force is responsible for doing work. **Pushing and pulling are examples of forces**. The box will not move until a force is exerted on it in form of a push or a pull. A moving object will not stop until a force is applied in the direction opposite to its motion to change its speed.

A force can make a stationary body move. It can also stop a body on motion or change its direction of motion.

Force is that which changes a bodyâ€™s state of rest or constant speed in a straight line.

Effects of forces

Force is not visible, we can only observe it by the effects it produces on objects it is exerted. Some of the actions or effects of forces are:

(i) a force can change a bodyâ€™s state of rest.

(ii) a force can change the speed of a body moving in a straight line.

(iii) a force can cause a moving object to change its direction.

(iv) a force can cause deformation of materials either by bending, twisting, stretching or compression.

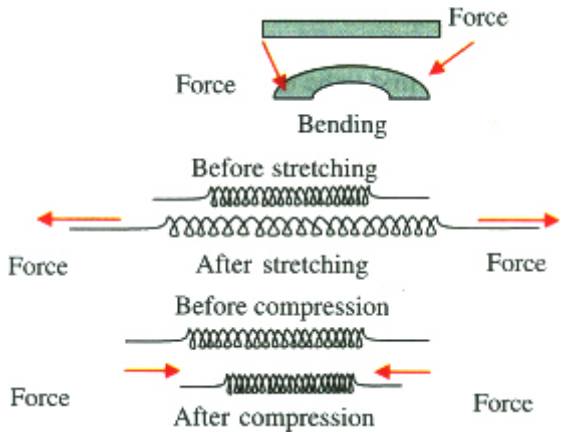


Figure 3.1 Some effects of forces

Types of forces

All known forces in the universe can be divided into two kinds: **force field** (non- contact force) and **contact forces** or **mechanical forces**.

Force field

Force field is the region or space around a source (mass, charge or magnet) where the effect of a force due to the source can be felt.

Force field acts through distance without touching or being in contact with the object, therefore, they are also called **non – contact force** or **force at a distance.** The strength of a force field at a point in the field reduces as the point moves away from the source of the field. Examples of force fields are:

- gravitational force field
- magnetic force field
- electric or electrostatic force field
- nuclear force field (strong forces and weak forces)

(a) Gravitational force field

This is the force which exists between two or more particles (objects) which are separated by a distance in space. Gravitational force field is responsible for the pulling of objects vertically downwards toward the centre of the earth. It keeps us on the earthâ€™s surface when you jump up you are pulled back to the earth by gravitational force. It keeps the planets in their orbits round the sun and prevents objects within the earthâ€™s gravitational field from escaping into the outer space. It is the weakest of the force field named above and the first to be

discovered because it acts through long distances.

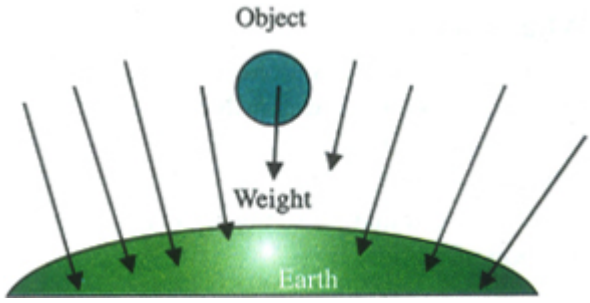


Figure 3.2 Gravitational force field around the earth

(b) Magnetic force field

When a magnet is brought near small iron nails, it will pull or attract the nails to itself. The force which pulls the iron nails to the magnet, is called the **magnetic force.** The space around a magnet where the effect of the magnet is felt is the magnetic force field.

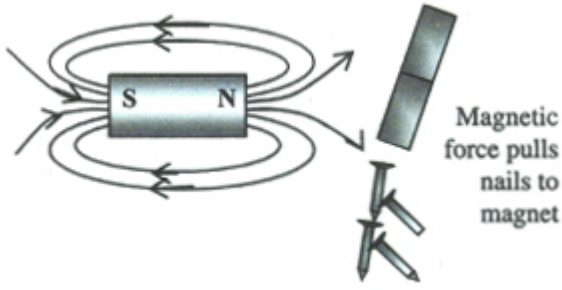


Figure 3.3 Magnetic field forces

(c) Electric force field:

The space around a charged body is surrounded by invisible lines of force called **electric field.** This exerts force on other charged particles, attracting or repelling them. The force exerted by a charged particle on other charges is called electric force. If one end of a pen or plastic ruler is rubbed on a dry hair or wool, it will attract tiny pieces of paper. The electric force produced by the charged pen pulls the small pieces of paper to itself even when they are not in contact. Electric force exists anytime two charged particles are separated by a distance in space or when a charged object is brought closed to an uncharged object. Electric force is related to magnetic force, in fact, they combine to form an electromagnetic force.

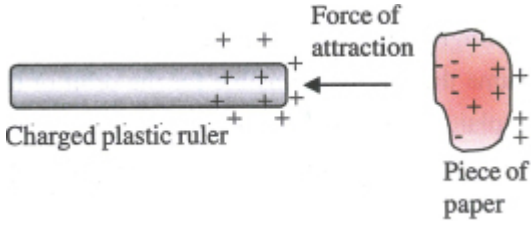


Figure 3.4 Electric force field

(d) Nuclear force field:

A nuclear force is the force that binds all the particles of the nucleus together. The particles in the nucleus are protons and neutrons. They are of two types, the **strong** and **weak nuclear forces.** Nuclear force is the strongest known force that exists in the universe though it acts through short distances.

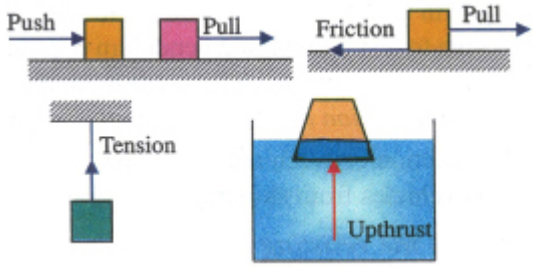


Figure 3.5 Examples of contact or mechanical forces

Contact or mechanical forces

Forces which act only when they are in contact or in touch with another body, are called mechanical or contact forces. Examples of contact forces are **pushing, pulling, tension, upthrust, friction,** etc.

Summary

- Force is that which changes a bodyâ€™s state of rest or constant speed in a straight line.
- Force field is the region or space around a source where the effect of a force due to the source can be felt. Examples of field forces are:
  - gravitational force field
  - magnetic force field
  - electric or electrostatic force field
  - nuclear force field (strong forces and weak forces)
- Forces which act only when they are in contact or touch another body are called mechanical or contact forces.

Practice Questions 3a

1. What is a force? State the effects of force.
2. Distinguish between force field and mechanical force.
3. Name the force responsible for the orbit of the planets round the sun.
4. Explain why a rubbed plastic ruler attracts small pieces of paper.
5. What is a force field? Give **two** examples of force field and **four** examples of contact or mechanical force.

6. Define force and state its unit. State four effects of a force.
7. Explain how weight is a consequence of gravitational force field.

FRICTION

OBJECTIVES

At the end of the lesson, students should be able to:

- identify which force slows down and finally stops a moving body;
- identify a force resisting the motion between two surfaces in contact and moving relative to each other;
- state the methods of reducing friction.

An object in motion does not continue to move forever. A rolling tyre left to move on its own will soon come to rest; a swinging pendulum opposed by air resistance comes to rest gradually. *When an object moves, rolls or slides against another, a force acts against it, in the direction opposite to that of the motion of the object, until it stops moving*. This force is called **friction.**

The friction between our shoes and the ground keeps us from slipping on the floor. Friction prevents vehicles from skidding, nails and screws are held in wood by friction.

Friction is the resisting force, which acts when two surfaces in contact move, or slide against each other.

Alternatively, friction is the force which resists (opposes) relative motion of two surfaces in contact.

Since friction resists motion, its direction is opposed to the motion of the object.

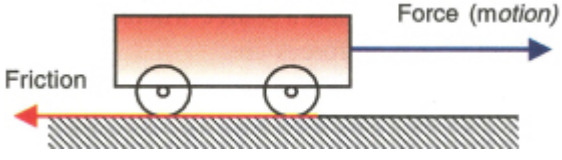


Figure 3.6 Friction opposes motion

Types of friction

There are two types of friction, they are:

- the **static** or **limiting friction**
- the **kinetic** or **dynamic friction**

Static friction:

This is friction which tends to prevent a stationary body from moving. A body at rest will not move until the static friction is overcome. The magnitude of static friction increases from zero until it reaches a maximum. The maximum static friction is called **limiting** or **starting friction**.

The limiting friction is that which exists between two surfaces when one is about to move relative to the other.

Kinetic or dynamic friction

The direction of the kinetic friction is opposite to the direction of motion of the body. If a body slides over another the kinetic friction is called a **sliding friction.** It is called **rolling friction** when a body rolls relative to another. Rolling friction is much less than sliding friction. In general, kinetic friction is always less than the static friction.

Kinetic friction is the friction, which exists between two surfaces moving relative to each other with a constant speed.

Nature and laws of friction

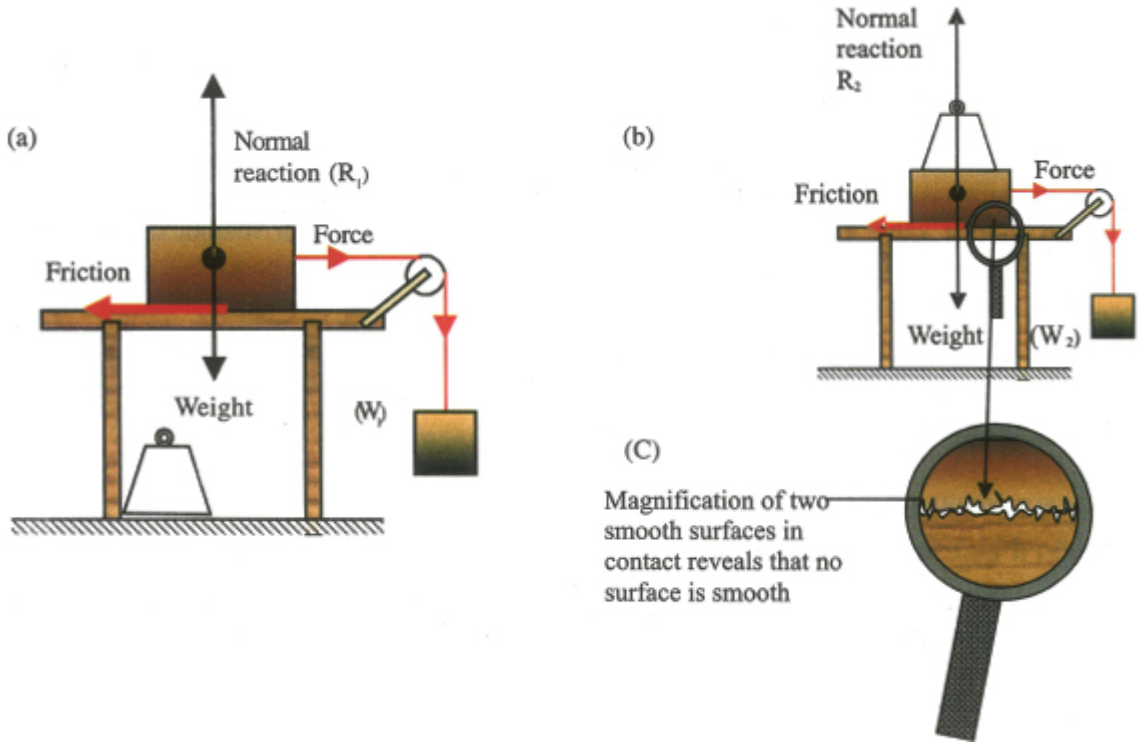


Figure 3.7 Friction resists motion of two surfaces in contact

Friction depends on the nature of the surfaces in contact. The degree of roughness or smoothness of the surfaces in contact determines the size of the friction. Friction is high if two surfaces in contact are rough surfaces and low if the two surfaces in contact are smooth surfaces. In practice, no surface is smooth. Very smooth surfaces when magnified many times look rough. (See Figure 3.7c.) The nature of friction can be studied using Figure 3.7.

When a force is exerted on the body, friction opposes the motion of the body to stop it from moving. The forces acting on the body are balanced if it does not move (friction is equal to the applied force and the normal reaction is equal to the weight). If the applied force is increased, friction also increases, however, friction does not increase

indefinitely and it will soon reach its limit or maximum value. The maximum static friction is called **limiting friction.** If the applied force is increased a little beyond the limiting friction the body begins to move or slide over the tables surface. Once the body begins to move the **static friction** is replaced by **kinetic** or **dynamic friction.** Further experiments reveal that adding more weights to the body increases the frictional force. Figure 3.7b illustrates this; however, *friction does not depend on the area of the surface in contact*.

Coefficient of friction (Î¼)

The weight of the block exerts force on the table; the table resists this force with an equal and opposite force called **normal reaction.** As the name implies it acts normally to the surface of the table.

Coefficient of friction is the ratio of the limiting friction to the normal reaction.

$$\text{Coefficient of friction} = \frac{\text{Limiting friction}}{\text{Normal reaction}}$$

$$\mu = \frac{F}{R} \quad \text{and} \quad F = \mu R$$

The equations above show that friction is proportional to the normal reaction (R). The constant of proportionality is called the **coefficient of friction** (Î¼). Friction increases with coefficient of friction and the value is high when the surfaces are rough and low for smooth surfaces. The coefficient of friction varies depending on the nature of two surfaces in contact.

The unit of frictional force or friction is Newton.

The unit of normal reaction is Newton also. Most times normal reaction has the same value as the weight of the body in question.

Coefficient of friction has no unit.

Friction = Minimum force needed to move the box = 35 N

Worked examples

1. A wooden box of mass 10 kg rests on a rough horizontal table. A horizontal force of 35 N is just sufficient to make it slide across the table surface calculate the coefficient of friction, (g = 10 m s^{-2})

Solution

$$\text{Coefficient of friction} = \frac{\text{Friction}}{\text{Normal reaction}}$$

Weight of wooden box = mass × gravity = Normal reaction = 10 × 10 = 100 N

$$\mu = \frac{35}{100} = 0.35$$

2. A block of mass 25 kg was made to slide on a rough horizontal ground. If the coefficient of friction is 0.5, find the frictional force between the ground and the block. ($g = 10\ m\ s^{-2}$)

Solution

$F = \mu R$

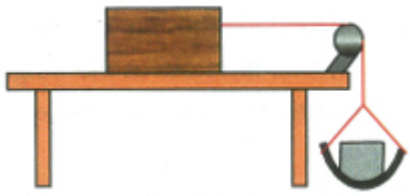
Normal reaction (R) = weight of the block

$= 25 \times 10 = 250\ N$

$F = 0.5 \times 250 = 125\ N$

Determination of coefficient of static friction (Ã¬)

Apparatus: Slider or block of wood, a cord or string, scale pan and pulley.



Procedure

(a) The set up above is used to determine approximately the horizontal force required to overcome static friction.

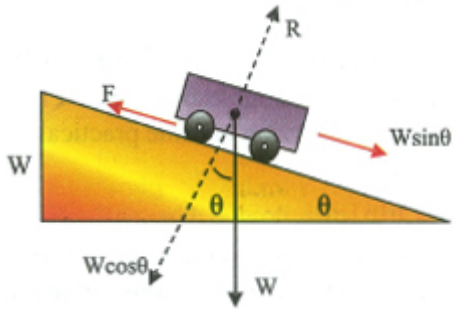
(b) Weigh the slider or the wooden block and record it as W. The normal reaction is equal to the weight if the two surfaces are horizontal.

(c) Weigh the scale pan and add weights in steps until the slider is just about to move relative to the other surface. The table or the horizontal platform should be tapped gently each time a new weight is added to the scale pan.

(d) Determine and record the total weight of the scale pan as P.

(e) Increase the weight of the slider gradually and repeating the experiment in step (i) – (iv).

(f) Plot a graph of Ï against W and determine the slope (s) of the graph. The slope represents the coefficient of static friction.



Friction on inclined plane

When W is resolved vertically in the opposite direction to normal reaction R, we have W cos $\hat{I}_{\text{¸}}$.

When W is resolved horizontally in the opposite direction to force F, we have W sin $\hat{I}_{\text{¸}}$.

The limiting or starting friction of an inclined plane depends on the angle $\hat{I}_{\text{¸}}$ of the inclined plane. The angle $\hat{I}_{\text{¸}}$is called the angle of friction. Friction is reduced if the angle of friction is increased.

When the body is about to slide, the forces acting on the slider or the wooden block are balanced. F = Wsin $\hat{I}_{\text{¸}}$ and R = Wcos $\hat{I}_{\text{¸}}$

$$\text{Coefficient of friction } (\mu) = \frac{F}{R}$$

$$\mu = \frac{W\sin\theta}{W\cos\theta} = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

The coefficient of friction Î¼ for an inclined plane with angle of friction Î¸ is given by:

$$\hat{I}\frac{1}{4} = \tan \hat{I}_{\text{¸}}$$

The laws of solid friction

1. Friction resists relative motion between two surfaces in contact. Its direction is opposite to the direction of the force causing the motion.
2. Friction depends on the degree of roughness or smoothness of the surfaces in contact. Rough surfaces in contact have high friction and smooth surfaces have low friction.
3. Kinetic friction is independent of the relative speed between the two surfaces in contact.
4. Friction depends on the normal reaction between the two surfaces in contact.
5. Friction increases as the weight of the body increases.
6. Kinetic friction is always less than static friction.

For any given pair of surfaces in contact, the ratio $\frac{\text{Frictional force}}{\text{Normal reaction}}$ = a constant

8. Friction is independent of the area of the surface in contact but on

the nature of the surface.

Disadvantages of friction

Friction is sometimes a nuisance because it results in waste of energy and low efficiency in machines. Energy is lost as result of heat produced when two surfaces rub against each other. Some of the disadvantages of friction are:

- friction always resists relative motion of two surfaces in contact.
- friction causes wear and tear of machines and engine parts as they rub each other.
- friction reduces the efficiency of a machine, because it wastes useful energy by converting them to heat.

Methods (ways) of reducing friction

Friction can be troublesome since it reduces the efficiency of machines. There is need to reduce or eliminate friction in some practical machines. The following are different ways friction can be reduced:

1. Lubrication

Lubricants like oil and grease are used to prevent two surfaces from coming in direct contact with each other. This is called **lubrication**. Lubricating moving parts of machine with oil reduces wearing and tearing of the parts and minimizes loss of energy in the form of heat.

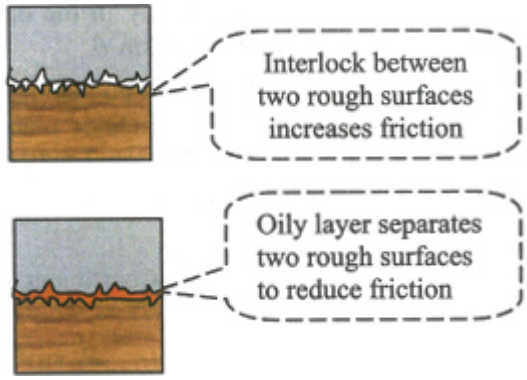


Figure 3.8 Lubrication minimizes friction

2. Using rollers

Rolling friction is much less than the sliding friction. When an object rolls instead of sliding, friction is reduced. Rollers in form cylinders are used to reduce friction between two surfaces sliding against each other. Ball bearings use iron balls as rollers to reduce friction between two surfaces moving over one another. The action of rollers in the reduction of friction is illustrated in Figure 3.9.

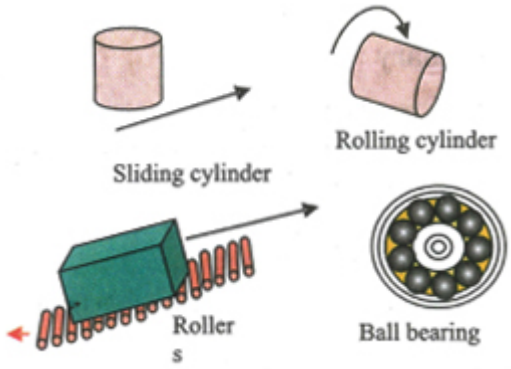


Figure 3.9 Friction is reduced when object rolls than sliding

3. Streamlining: Cars, aeroplanes, rockets etc. are streamlined to reduce friction in fluids. A streamlined object has pointed head and slightly curved bodies to reduce surface area in contact with fluid during its motion.

4. Polishing or smoothening the surfaces reduces friction. Smoothening surfaces reduces the interlock between them, therefore friction between the surfaces is reduced.

Advantages of friction

Friction is very useful despite its disadvantages. Some of the uses of friction are:

(a) Friction helps us to walk. Friction between our feet and the ground assists us to walk without slipping.

(b) Friction makes griping of objects possible. Friction helps in joining nut and bolt or nail and wood together.

(c) The friction between the brake drum and the lining of the brake helps to stop a moving car when the brake is applied.

(d) Tyres with specially designed grooves and channels grip firmly on a road surface because the grooves increase friction between the tyre and the ground.

(e) The ladder stays on the wall without slipping or skidding because friction between the ladder and the wall prevents skidding.

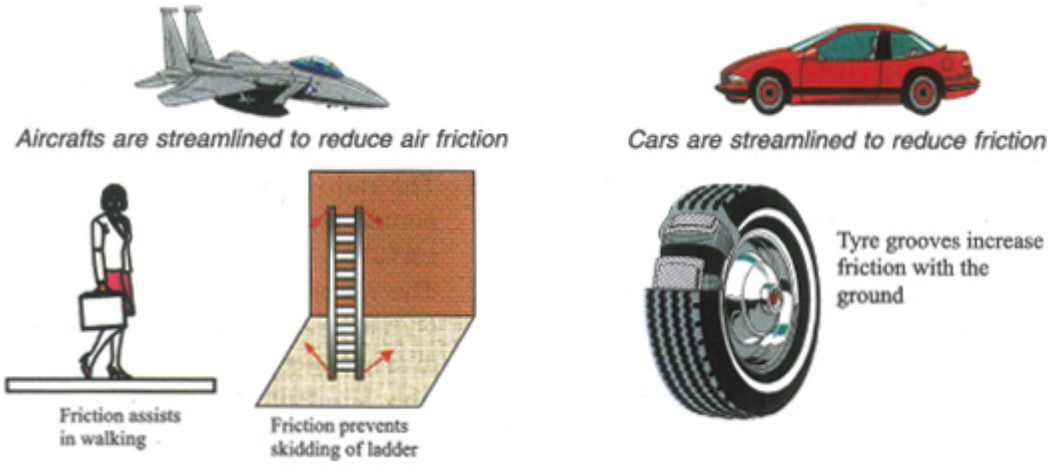


Figure 3.10 Uses of friction

Summary

- Friction is the force which resists (opposes) relative motion of two surfaces in contact.
- The limiting friction is that which exists between two surfaces when one is about to move relative to the other.
- The friction between two surfaces moving with a constant speed relative to another is called kinetic friction.
- The ratio of the limiting friction to the normal reaction is called the coefficient of friction.

Practice questions 3b

1. (a) Explain the term friction.
   (b) State three advantages and five uses of friction.
2. Describe the behaviour of friction as the applied force increases.
3. No surface is absolutely smooth. Explain.
4. A box of mass 48kg is caused to slide across a cement floor. If the coefficient of friction between the floor and the box is 0.62, calculate the minimum force required move the box.
5. Explain why modern cars are streamlined. Why is it necessary to minimize friction?
6. (a) What is friction?
   (b) Distinguish between static and kinetic friction.
   (c) State and explain three ways friction can be reduced in a machine.
7. (a) State the laws of solid friction.
   (b) Describe an experiment to determine the coefficient of limiting or starting friction between two wooden surfaces.
   (c) A wooden block of weight 500 N lies on a table with rough

surface. When a horizontal force of 100 N is exerted on the block, it begins to slide along the surface of the table. What is the coefficient of static friction between the wooden block and the tableâ€™s surface?

Past questions

1. Which of the following statements about the concept of solid friction is **NOT** true?
   A. It always acts in the direction of motion.
   B. It causes wear and tear in car tyres.
   C. It depends on the nature of the surfaces in contact.
   D. It is independent of the area of the surfaces in contact.
   E. It reduces the efficiency of the machine.

   NECO

2. Which is **NOT** one of the laws of the solid friction?
   A. The frictional force between two surfaces opposes their relative motion.
   B. The ratio of frictional force to the normal reaction varies for two given surfaces.
   C. The ratio of frictional force to the normal reaction is constant for two given surfaces.
   D. The limiting frictional force is independent of the area of the surface in contact.
   E. Dynamic frictional force is independent of the relative velocity of the surfaces in contact.

   NECO

3. What is the coefficient of static friction between a load of mass 2 kg and a horizontal surface, if the limiting frictional force is 10N? (g = 10 m^{-1})
   A. 0.2
   B. 0.5
   C. 2.0
   D. 5.0
   E. 8.0

   NECO

4. Which of the following is not a consequence of the force field?
   A. Weight
   B. Surface tension
   C. Gravitational pull
   D. Magnetic force
   E. Electric force

   WAEC

5. Which of the following is not an example of a force?
   A. Tension
   B. Weight
   C. Friction
   D. Mass
   E. Thrust

WAEC

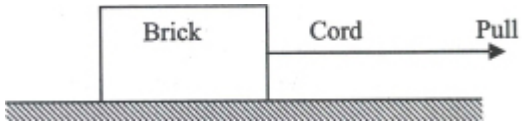
6. The frictional force between two bodies
   A. exists only when there is relative motion or tendency for motion.
   B. acts so as to oppose the motion.
   C. depends on the normal reaction between the two surfaces.
   D. is relatively independent of the area in contact.
   E. have all these characteristics.

JAMB

7. Which of the following statements about friction is **NOT** correct?
   A. The force of kinetic friction is less than the force of static friction.
   B. The force of kinetic friction between two surfaces is independent of the areas in contact provided that the normal reaction is unchanged.
   C. The rolling friction between two surfaces is less than the force sliding friction.
   D. The angle of friction is the angle between the normal reaction and the force friction.
   E. Friction may be reduced by lubrication.

JAMB

8. A brick at rest on a horizontal table is pulled by a horizontal cord, as shown in Fig. 2. The force of friction on the brick



   A. increases if the pull increases but the brick does not move.
   B. directly horizontal to the right.
   C. decreases if an identical brick is placed on the first.
   D. is zero if the brick is pulled hard enough to make it slide.
   E. changes if the brick is turned on its side.

JAMB

9. (a) State the laws of solid friction.
   (b) (i) Describe an experiment to determine the coefficient of static friction between two solid surfaces.
   (ii) State **one** precaution that should be taken to ensure an accurate result.
   (c) State **two** (i) disadvantages of friction (ii) methods of reducing

friction.

NECO

10. State **two** (i) laws of solid friction
    (ii) advantages of friction
    (iii) disadvantages of friction (iv) methods of reducing friction.