JOURNAL OF RESEARCH IN ENGINEERING

VOL. 4, NO. 4, 2007

INTERNATIONAL RESEARCH AND DEVELOPMENT INSTITUTE

JOURNAL OF RESEARCH IN ENGINEERING

ISSN 1597-8001

Volume 4, Number 4, 2007

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Journal of Research in Engineering, Volume 4, Number 4, 2007.
ISSN 1597-8001

FRICTIONAL FORCE: SOURCE OF MISCONCEPTION AMONG SENIOR SECONDARY AND TERTIARY STUDENTS.

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ABSTRACT

Frictional force is a source of misconception among students, as teachers know from daily experience. This paper attempts to illustrate in a relatively simple context, several techniques for analyzing the forces on objects and their resulting motion. Conceptual problems involving frictional force experienced by bodies moving on a flat surface, inclined plane and those that undergo rotational motion are discussed with simple examples given. Suggestions on teaching strategies based on problem solving in order to ensure meaningful learning of this topic are also provided.

***Keywords:** Frictional force, rotational motion, techniques, strategies, problem- solving*

INTRODUCTION

From daily experience, teachers have identified friction; a Physics topic as a source of misconception among secondary school students .This topic has continued to give students serious problems when they are faced with basic situations. Many of these problems were induced by common sense. Students attempt to solve friction related problems by trial and error method or by invoking a solution which they learnt in the class to a problem which they wrongly assumed to be similar to the one they are solving. They tend to solve problems relating to friction by selecting mathematical formulae to relate variables in the problem (Agbayewa, 1997). This picture was also found among university students, and other students in higher institutions. Because of the importance of dynamics in Physics, the amount of time that may be spent on this subject is very significant when compared to other Physics topics. Nevertheless, secondary and tertiary students continue to show serious problems when faced with basic situations, especially those involving the frictional forces on bodies on an inclined place especially rolling bodies. Misconceptions on this area of physics are usually experienced by these students. Many of the students tend to use common sense to solve problems related to this area of Physics. It is important to state that a number of the students do not know that if there is no friction between rolling objects and the plane, the sphere would slid rather than roll. Friction must be present to make the sphere roll. If the object is perfectly rigid, it is in contact with the surface at a point, and the force of friction will act parallel to the plane. The point of contact of the sphere at each instant does not slide but moves perpendicular to the plane (first down and then up) as the sphere rolls (Salazar and Arriandiaga, 1990). Some strategies that can be used to solve specific problems relating to this very important topic can be seen in the literature (Sousa and Pina, 1999). Any strategy used must confront students with physical situations where they can discuss relevant features of the frictional force, like its origin, its direction, and eventual effects on translation and rotation and the comparative motion of sliding blocks and rolling objects

METHODOLOGY

The participants at a workshop during a National conference who included Physics teachers, senior secondary and tertiary students were asked questions about basic concepts such as the direction of frictional force, normal force at an interface, Newton' third law, in the context of situations involving rolling objects. The responses obtained revealed some difficulties being experienced by the participants. These difficulties are discussed with relevant examples.

DISCUSSION

The results from a promoted workshop during a National conference (Carvalho and Sousa, 2002) show that majority of participants who were physics teachers, senior secondary and tertiary students seem to lack understanding a bout concepts such as the direction of frictional force, normal forces at an interface and Newton's third law especially in the context of situation involving rolling objects. The difficulties expressed by these teachers and students on this topic prompted some explanations given with examples in this paper on each of the following questions which were asked by the participants (students and teachers)

(a)Are frictional forces always opposite to the direction of the velocity at the instantaneous point(s) of contact?

(b)Are static, kinetic and rolling frictions equivalent designations for friction?

(c) Is a rigid cylinder rolling without slipping on a rigid horizontal surface always subjected to a frictional force?

(d) Is a body standing on a horizontal surface always subjected to a normal force given by the gravitational force acting on it (weight)?

The results from the workshop show that majority of the participants seem to know that frictional force does not always have the same direction as the motion. This fact could be related to some examples like a person walking, or a passenger standing in a bus as it accelerates. The response to the second question (b) could be gotten from the basic concepts of friction, frictional force and its direction. Static and kinetic frictions refer to static and sliding objects respectively. Rolling friction is used to describe rolling objects. Question (c) explicitly introduce a problem of frictional force on rolling bodies and for a rigid cylinder rolling without slipping on a horizontal surface, there is a common idea that whenever there is motion, there must be a frictional force. The fact is that there is an absence of a frictional force and this is difficult to understand because people know that objects do not move forever; what they don't know is that this fact is due to rolling friction that comes from the deformation of objects or surfaces. (Domenech A, Domenech T and Cebrian J, 1987), and here we are dealing with ideal (non-deformable) objects. In response to question (d), a block which is at rest on a flat tabletop is considered. One of the forces acting on the block is its weight ($F_g = mg$), the force of the earth's gravitational attraction which pulls the object toward the earth's centre. The block's weight is equal and opposite of a normal Force N, a contact force perpendicular to the surface in contact. So a body standing on a horizontal surface is always subjected to a Normal force. Teachers must realize that the main thing about rolling objects is that a rotation of the body takes place. This implies that the physical and mathematical description of rolling objects implies not only the fundamental equation for translational motion

$$\sum_i F_i = ma \text{ ------------------------ } (1)$$

but also the fundamental equation for rotational motion is

$$\sum_i M_{Fi} = I\alpha \text{ ----------------------- } (2)$$

In order for students to understand this, they must be introduced to the basic concepts of *angular speed* and *angular acceleration, moment of inertia* of a body (inertia to rotation) and eventually *torque*. They must have a good conceptual understanding and subsequently a mathematical understanding of rotational motion. These topics must be fully discussed with students. Examples and counter-examples must be used in the classroom because of the difficulties shown by students in learning these topics. In addition to all the problems already suggested in textbooks, which are, of course, valuable contributions, some relevant and stimulating examples, which aim directly at the gaps pointed out in the introductory study of frictional forces, are presented in this paper. Example1: Problem Involving Normal Reaction, Applied force, Frictional force, Weight and Tension.

The Problem: A block of mass M_A = 7.00kg is connected to another block of mass M_B = 4.50kg. The two masses are pulled along a level table by a horizontal force of 29.0N as shown in figure 1b.A constant frictional force acting between the 7.00kg mass and the table is 1.35. The 4.50kg slides without friction. Calculate the acceleration of the two blocks and tension in the string that connects them.

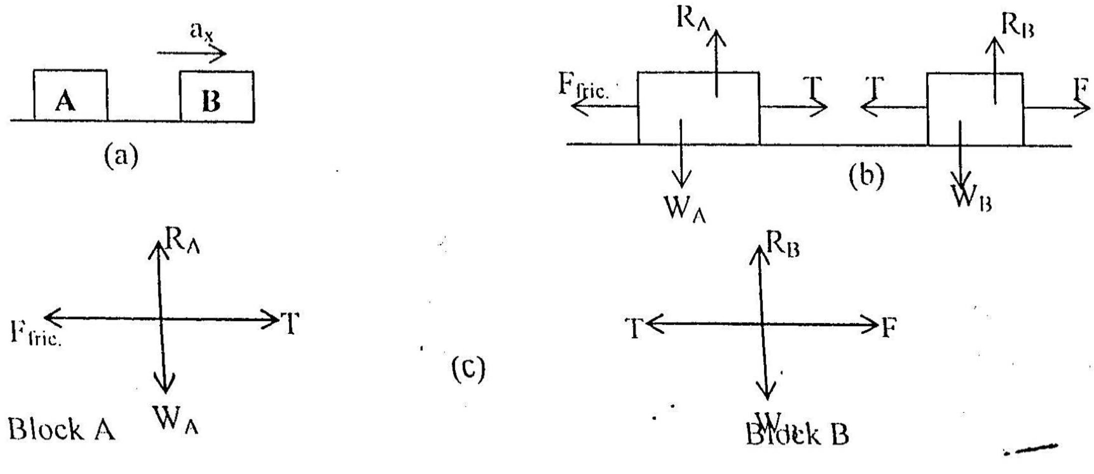

Fig. 1

Fig 1(a): Blocks A and B are being pulled along a horizontal surface by the applied force F. The motion of these blocks is in the positive x-direction
(b): Forces acting on blocks A and B are represented
(c): Free-body diagrams for blocks A and B
We write the Newton's second law of motion in both x and y directions for each block i.e.

$\sum F_y = ma_y$ ---------------- (3) for each block and

$\sum F_x = ma_x$ ---------------- (4) for each block

But all acceleration in the y-direction is zero since the block has a constant y-direction, thus, the normal force can be determined as follows:

$$N_A - W_A = 0$$
$$N_A = W_A$$
$$= M_A g$$
$$= (7.0kg)(10.00Nkg^{-1}) = 70N$$

In order to find the equations for the horizontal motion, we need to analyze the horizontal motion of the blocks. Because the method is the same for each, we will write equations for blocks A and B side by side.

$\sum F_{Ax} = M_A a_{Ax}$ ------------------ (5) $\sum F_{Bx} = M_B a_{Bx}$ ------------------ (6)

$T - F_{fric.} = M_A a_{Ax}$ ------------------ (7) $F - T = M_B a_{Ax}$ ---------------- (8)

Equations (7) and (8) are with two unknowns T and a_{Ax}. Also, since the blocks are pulled by a common force, they move with a common velocity and common acceleration, so we can set

$$a_{Ax} = a_{Bx} = a_x$$

The equations then become:

$T = F_{fric.} + M_A a_{Ax}$ ----------------------- (9)

$F = (F_{fric.} + M_A a_{Ax}) = M_B a_{Ax}$ .... (10)

Equations (7) and (8) can be solved simultaneously by solving the Block- A equation for T, and substituting the resulting expression into the block- B equation. Then the unknown T is eliminated to solve for the acceleration.

$$F - F_{fric.} = (M_A + M_B)a_x$$

$$a_x = \frac{F - F_{fric.}}{M_A + M_B}$$

$$= \frac{29.00N - 1.35N}{7.00kg + 4.50kg}$$

$$a_{Ax} = 2.404ms^{-2}$$

We can now substitute back into equation (7) to find the tension; T

$$T = 1.35N + (7.00kg)(2.40ms^{-2})$$
$$= 18.15N$$

Example 2: Friction on an Inclined Plane

A 12kg block rests on a 30° inclined plane. If $\mu_k = 0.1$, what push P parallel to the plane and directed up the plane will cause the block to move (a)up the plane with constant speed and (b)down the plane with constant speed?.

Solution:

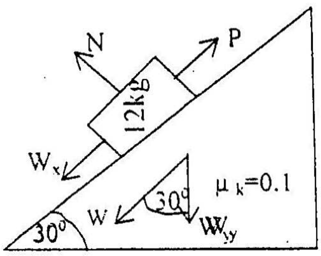

Fig 2a

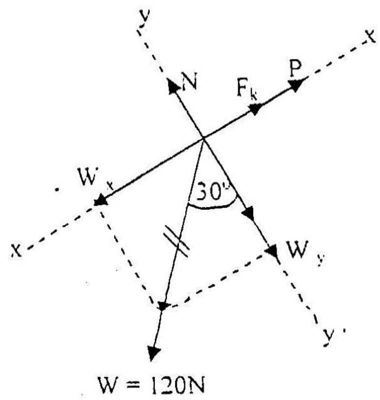

Fig2b

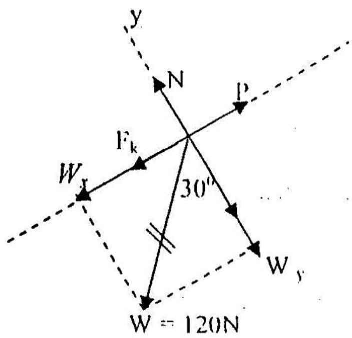

Fig2c

Fig. (2a) shows the forces acting on a body on an inclined plane
Fig.2 (b) and (c) show free-body diagrams and the resolution of the weight force W into its components (b) when the body moves up the plane and (c) when the body moves down the plane.
Applying the first condition for equilibrium, we obtain

$$\sum F_x = 0 \qquad P - f_k - W_x = 0 \text{ ------------------- (11)}$$

$$\sum F_y = 0 \qquad N - W_y = 0 \text{ ------------------- (12)}$$

$$W_x = 120N\sin 30^o = 60N$$

$$W_y = 120N\cos 30^o = 103.9N$$

Substitution of the latter into equation 10 allows us to solve for the normal force. Hence

$$N - 103.9 = 0$$

$$N = 103.9N$$

The push P required to move up the plane is from equation 9,

$$P = f_k + W_x$$

But $f_k = \mu_k N$, so that

$$P = \mu_k N + W_x$$

Substituting known values for μ_k, N and W_x, we obtain

$$P = (0.1)(103.9) + 120\sin 30^o$$

$$= 10.39N + 60N$$

$$= 70.39N$$

Note: the push up the plane in this case must overcome both the frictional force of 10.39N and the 60N component of the weight down the plane.
Example 3: A circular cylinder has a mass m and was released. It rolled without slipping down a plane inclined at 30° to the horizontal, find the acceleration of the cylinder.

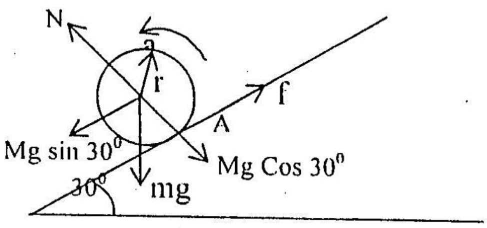

Fig. 3

The forces acting on the cylinder are: the weight mg acting downward which is split up into its components parallel to and perpendicular to the plane: the Normal force N exerted by the plane, the frictional force f attempting to prevent motion.
Since the cylinder does not lift from the plane, we have

$$N = mg\cos 30^o \text{ ------------------------ (13)}$$

Further, by Newton's second law,

$$mg\sin 30^o - \mu N = ma \text{ ----------------- (14)}$$

$$mg\sin 30^o - \mu mg\cos 30^o = ma \text{ ----------------- (15)}$$

Rotation about the centre of the cylinder also takes place since we are dealing with rotations of distributed masses, we have

$$\Gamma = I\alpha \text{ ---------------------- (16)}$$

Where Γ = torque, I = moment of inertia α = angular acceleration
If the axis is taken about the centre of the cylinder, then the only torque acting on the cylinder is μNr due to the frictional force μN. Then,

$$\mu Nr = \mu rmg\cos 30^{\circ} = I\alpha \text{ ---------------(17)}$$

where r is the radius of the cylinder.
Since no slipping takes place, the point A is instantaneous at rest, Hence

$$a = r\alpha \text{--------------------------- (18)}$$

and,

$$mg\sin 30^{\circ} - \mu mg\cos 30^{\circ} = ma \text{ ---------- (19)}$$

$$\frac{\mu rmg\cos 30^{\circ} = Ia}{r} \text{ ----------- (20)}$$

or, multiplying (12) by r^2, and (13) by r, we have

$$mg\,r^2\sin 30^{\circ} - \mu rmg\cos 30^{\circ} = ma\,r^2 \text{-------(21)}$$

$$\mu m\,r^2 g\cos 30^{\circ} = Ia \text{ --------(22)}$$

Substituting (15) into (14), we have.

$$mg\,r^2\sin 30^{\circ} - Ia = mar^2$$

Or

$$a = \frac{mg\,r^2\sin 30^{\circ}}{I + m\,r^2}$$

But I for solid cylinder, $I = 1/2mr^2$
Therefore.

$$a = \frac{mg\,r^2\sin 30^{\circ}}{1/2mr^2 + mr^2}$$

$$a = 2/3\ g\sin 30^{\circ}$$

Example 4: A bowling ball of mass M and radius R is thrown along a level surface so that initially (t=0) it slides with a linear speed v_o but does not rotate. As it slides, it begins to spin, and eventually rolls without slipping. How long does it take to begin rolling without slipping?
Solution: The free-body diagram is shown in fig. (4), with the ball moving to the right.

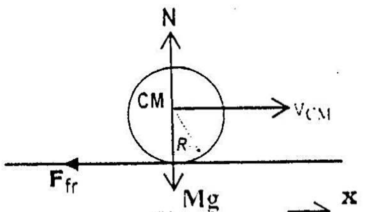

Fig. 4

Newton's second law for translation gives

$$Ma_x = \sum F_x = -\mu_k N = -\mu_k Mg \text{ ------------ (23)}$$

Where μ_k is the coefficient of kinetic friction the ball is sliding. The frictional force does two things: it acts to slow down the translational motion of the CM(the centre of mass of the body): and it immediately acts to start the ball rotating clockwise. The velocity of the CM is

$$v_{CM} = v_o + a_x t = v_o - \mu_k gt \text{ ------------------ (24)}$$

Next we apply Newton's second law for rotation about the CM. $I_{CM}\alpha_{CM} = \sum\tau_{CM}$

$$2/5MR^2\alpha_{CM} = \mu_k MgR \text{---------------------- (25)}$$

The angular acceleration is thus $\alpha_{CM} = 5\mu_k g / 2R$, which is constant. The angular velocity of the ball is given by

$$w_{CM} = w_o + \alpha_{CM}t = 0 + \frac{5\mu_k gt}{2R} \text{ --------------(26)}$$

The ball starts rolling immediate after it touches the ground, but it rolls and slips at the same time to begin with. It eventually stops slipping, and then rolls without slipping. The condition for rolling without slipping is that

$$v_{CM} = w_{CM}R \text{-------------------------(27)}$$

This condition is not valid if there is slipping. This rolling without slipping begins at a time $t = t_1$ given by

$$v_o - \mu_k gt_1 = +\frac{5\mu_k gt_1 R}{2R}$$

So,

$$t_1 = \frac{2\,v_o}{7\mu_k g}$$

TEACHING APPROACH

In order to solve problems involving friction, which is a basic problem, it is of utmost importance to analyze the problem and ask for a free body diagram. Demonstration method of teaching can be adopted so that while the problem is demonstrated, students are able to see how each force involved in the motion of the bodies act. In addition, it is important to treat the problem mathematically in order to analyze the consequences of the frictional force and other forces at the point of contact.

Example 1: Demonstration of the problem should be followed by the analysis of the two blocks using free-body diagrams showing the forces which are resolved vertically and horizontally in each case with the use of the second Newton's fundamental law which can be applied to generate necessary equations.

These equations can then be solved simultaneously in order to find the required quantity. Students should try not to memorize any of the equations involved in solving the problem because they may not be valid in other problem of frictional force. Instead, they should learn how to apply the procedures listed in the problem-solving strategy.

Example 2: Teachers should also demonstrate the problem in the laboratory or class so that the students can conceptualize the problem in order to make the problem-solving strategies that may be adopted easily understood. Analyzing the forces shown in fig. (2), the forces acting on the body are its weight, the Normal, and friction.

The direction of the acceleration of the body is certainly going to be along the surface of the incline. Although N and F_{fric} are parallel to the y-and x-axes respectively, the weight force W is parallel to neither. Hence, W must be resolved into its x and y components which can be accomplished through resolution by using the usual trigonometric identities and construction.

Example 3: This example is rather simple but shows the importance of a separate study of sliding and rolling objects, so teachers must be aware of this. This problem can be approached by first drawing the forces acting on the cylinder, in the free-body diagram. Attention should be paid to the forces producing a torque: only the frictional force does so. In descending motion, this torque accelerates the cylinder. However, for ascending motion, the rotation of the cylinder must decrease (i.e. it must have a 'negative' angular acceleration) which can only be achieved if the frictional force also points upwards. Teachers should also discuss this problem carefully with their students, and demonstrate a simple but very enlightening experiment to enhance better understanding of the students.

Example 4: The discussion of this problem in the class should involve the derivation of mathematical approach. Teachers should use an experimental model to demonstrate or simply let the students try by themselves because from experience, students do have a better understanding when they confront physical and mathematical reasoning with practical experience as mentioned by other investigators (Caldas and Saltier, 2001). It is suggested that when explaining this example, a conceptual approach should be started with by drawing the free-body diagrams representing the forces acting on the body. All necessary equations are then written and solved.

CONCLUSION

This paper has drawn attention to the fact that students tend to simplify problems concerning rigid bodies, by using the same reasoning they do with material particles. This leads frequently to misconceptions concerning the direction of the frictional force and the representation of forces in free-body diagrams, which are an obstacle to solving problems involving rotation. This problem also prevails in teachers. Students and teachers always look for a unique and general answer to this kind of problems, which does not exist. It is suggested that before basic concepts such as angular speed and acceleration, moment of inertia and torque are introduced in the classroom, teachers should avoid using definitions for the direction of the frictional force that apply only to specific situations such as sliding e.g. "the frictional force is opposition to motion" or "the frictional force points in the opposite direction to the motion" (Caldas and Saltier, 1999). Teachers should encourage their students to draw free-body diagrams, including not only the rigid body itself but also the surface (Puri ,1996), so that they can discuss both forces acting on the surface and on the body as well as the corresponding pairs of forces (Newton's third law of force pairs). Finally, this paper also drew attention to the fact that the learning of physics can be interesting and less difficult if problem-solving instructional strategy form a part of a comprehensive plan of physics instruction.

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