

Friction, Work, and Energy on an Inclined Plane

I. Purpose

In this experiment, we will observe a cart or block moving up an inclined plane at a constant speed and determine the force of friction on the cart/block. We will determine the work done on the object by an external force in the form of a hanging weight via a pulley. We will determine the work done by friction along with the change in potential energy of the cart/block. We will also explore the use of conservation of energy to determine the work done by friction.

II. Required Equipment

1. An incline plane apparatus equipped with a protractor to determine angle
2. A string which attaches to the cart/block and to a hanging mass holder
3. A meter stick
4. A calibrated mass hanger
5. Calibrated hanging masses

III. Theory

Two different methods will be used in determining the work done by friction. These methods include what we will refer to as the Force Balance Method and the Energy Method.

Case A: Frictional Force – Force Balance Method

Situation 1A: Cart/Block Moving up an Inclined Plane at Constant Speed

The situation for an object moving up an inclined plane is shown in Fig. 1. Since the car is not accelerating, the force on the car in the upward direction along the inclined plane must be equal in magnitude to the sum of the two forces \mathbf{F}_{\parallel} and \mathbf{f} which are parallel to the plane in a downward direction. In vector form, we can write this as, $\mathbf{F} = \mathbf{F}_{\parallel} + \mathbf{f}$, where \mathbf{f} represents the force of friction and \mathbf{F}_{\parallel} has magnitude $m_c g \sin \theta$ and represents the component of the cart/block's weight that is parallel to the plane and where m_c is the mass of the cart/block.

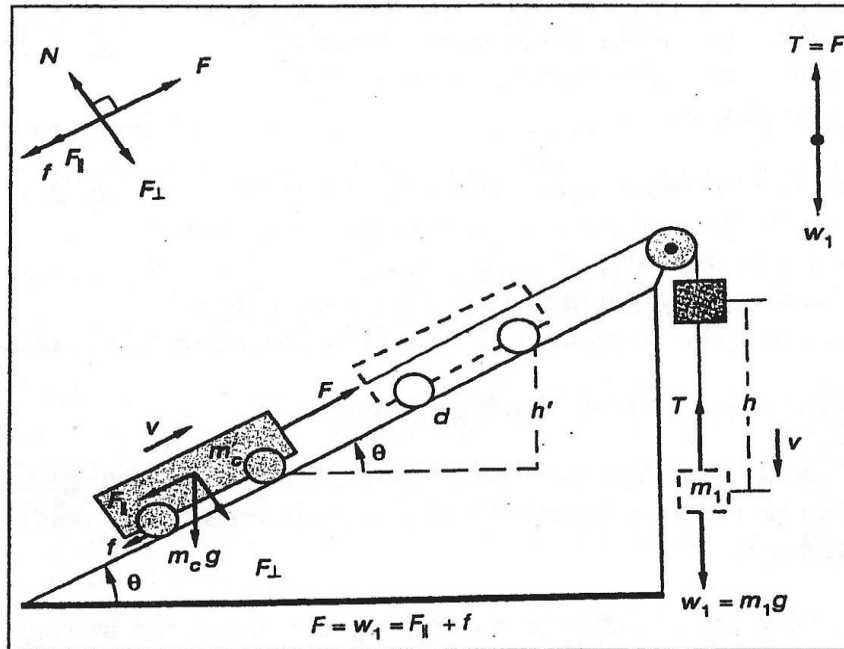


Fig. 1. Car moving up incline with constant speed.

Since the magnitude of F is equal to the weight force w_1 , we can write $w_1 = F_{||} + f$.

From this, we can see that by solving for f and expressing the other forces in terms of the experimental parameters, we have the following for the case where the cart/block is moving up the inclined plane,

$$f = m_1 g - m_c g \sin \theta \quad (1)$$

Situation 2A: Cart/Block Moving down an Inclined Plane at Constant Speed

For the situation where the object is moving down the inclined plane as shown in Fig. 2, we have a few differences in our procedure. Since the object is not accelerating, the force $F_{||}$ on the object in the downward direction along the plane must be equal in magnitude to the sum of the two forces F and f , which act in the direction up the plane. That is to say, $F_{||} = F + f$, where in this case the direction of f is up the plane. Since the magnitude of F is equal to the weight force w_2 , we can write, $F_{||} = w_1 + f$. As before, we can express f in terms of the experimental parameters. This time we get,

$$f = m_c g \sin \theta - m_2 g \quad (2)$$

In both cases, the frictional work on the object is given by

$$W_f = -fd \quad (3)$$

Where d is the distance the object moves. Note that the negative sign appears since the force of friction is in the opposite direction as the motion of the object.

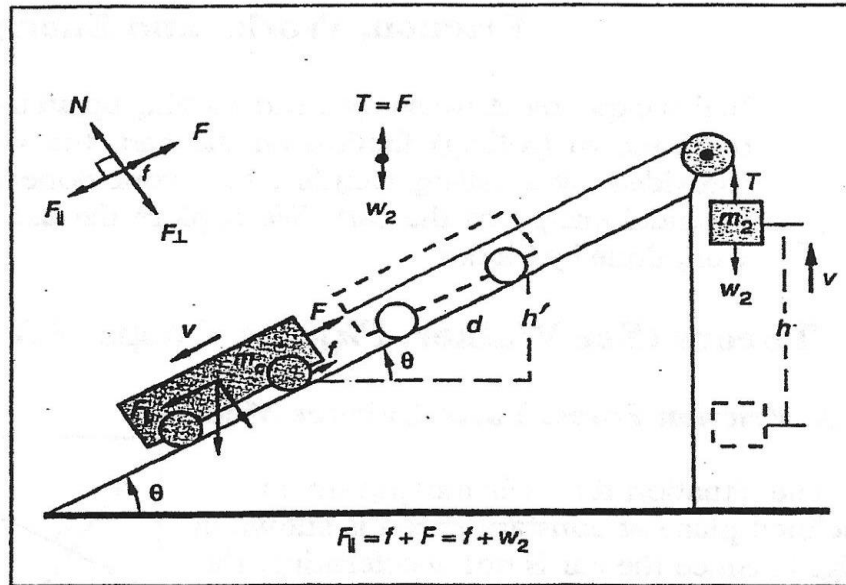


Fig. 2. Car moving down incline with constant speed.

If the object moves at approximately the same constant speed in both directions, one might think that the frictional force may have approximately the same magnitude in the two situations.

Case B: Work of Friction – Energy Method

We can look at frictional work in terms of the change in the potential energy of the cart/block. Since the object moves at constant speed, there will be no change in the object's kinetic energy during its motion.

Situation 1B: Cart/Block Moving up an Inclined Plane at Constant Speed

For the case of the cart/block moving up the plane, the increase in the object's potential energy, ΔU_c , is equal to the work done on it by non-conservative forces (the force, F , and the frictional force, f). We have, $\Delta U_c = Fd + W_f$, which gives us,

$$\Delta U_c = m_1gd + W_f$$

Solving for W_f , we have,

$$W_f = \Delta U_c - m_1 g d$$

But, $\Delta U_c = m_c g h'$, where h' is the change in the vertical height of the cart/block. So, we get,

$$W_f = m_c g h' - m_1 g d$$

or

$$W_f = m_c g d \sin \theta - m_1 g d$$

for the case where the object is moving up the incline plane.

Situation 2B: Cart/Block Moving down an Inclined Plane at Constant Speed

For the case of the cart/block moving down the plane, the potential energy in the cart/block decreases, hence we have, $\Delta U_c = -F d + W_f$, which gives us,

$$\Delta U_c = -m_2 g d + W_f$$

Solving for W_f , we get,

$$W_f = \Delta U_c + m_2 g d$$

But, $\Delta U_c = -m_c g h'$, where h' is the change in the vertical height of the cart/block. So, we get,

$$W_f = -m_c g h' + m_2 g d$$

or

$$W_f = -m_c g d \sin \theta + m_2 g d$$

for the case where the object is moving down the incline plane.

IV. Experimental Procedure

1. Using the laboratory scale, measure and record the mass, m_c , of the cart/block.
2. Arrange the incline plane, cart/block, and mass hanger as shown in Fig. 1. Set the angle of the incline plane to 30° . Note that if possible, the string attached to the cart/block should be parallel to the plane.

3. Add weight to the mass hanger so that the cart/block moves up the incline with a slow uniform speed when the car/block is given a slight tap. Record the total mass of the hanger and weights.
4. You will be asked to record the distance that the cart/block moves up or down the incline plane. To do this you can either marking the start/stop position on the incline plane or measure the distance that the mass hanger descends or ascends during the run.
5. With the cart/block positioned near the top of the inclined plane, remove enough weight from the mass hanger so that the cart/block descends down the incline with a slow uniform speed when the object is given a slight tap. Record the total mass of the hanger and the weights. Record the distance as before.
6. Adjust the angle of the inclined plane to 45° and repeat steps 3-5.

V. Analysis

1. Compute the frictional force f using equations (1) and (2) for the 30° angle for both the up and down situations, and enter the results on the data sheet. Calculate the discrepancy percentage between the two values.
2. Compute the work done by friction on the cart/block using equation (3) for the 30° angle for both the up and down situations and record the results on the data sheet.
3. Compute the frictional force f using equations (1) and (2) for the 45° angle for both the up and down situations, and enter the results on the data sheet. Calculate the discrepancy percentage between the two values.
4. Compute the work done by friction on the cart/block using equation (3) for the 45° angle for both the up and down situations and record the results on the data sheet.