7.6 Potential and Kinetic Energies

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Printed: Oct 31, 2013 1:24:55 PM
interTESS (Version 13.06 B200, Export 2000)

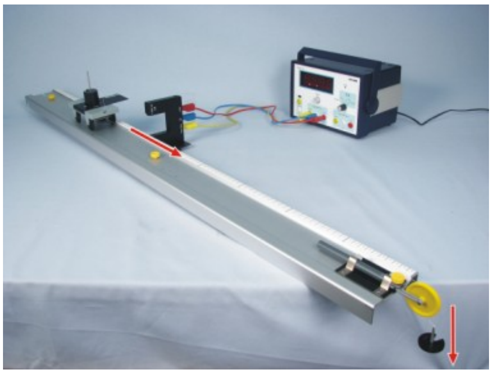
Task

Task

How great is the kinetic energy of a rolling car?

From an experimental car with mass mW which is on a track, and over a pulley hangs a weight which under gravitational pull has the potential energy $E_{pot} = m_g\ g\ h$. Here, h is the height over the ground and g is the gravitational acceleration. The weight on the line pulls the car and accelerates it. The weight reaches the ground after accelerating the car along the distance s, which corresponds to the initial heigth of the weight. Together, the weight and the car have a combined mass $m = m_W + mg$ and are brought together to the speed v_h. After this, the car continues moving without acceleration. Examine the speed, v_h, which the car reaches with the aid of the photoelectric gates and the timer.

The weight on the line in the gravitational field loses potential energy as it falls and moves the car. This potential energy can be determined based on the lost height of the weight. The energy is converted into the motion energy of the car and the weight. This experiment also determines what speed the weight and the car reach with the energy available. In this way the relation between speed and motion energy can be established. This motion energy is also called kinetic energy, E_{kin}.



Use the space below for your own notes.

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Additional Information

In this experiment, pupils should investigate and become familiar with the conversion of potential energy into kinetic energy. Here, an experimental car will be accelerated by a weight in the earth's gravitational field. The accelerating force is deactivated automatically after a given distance (or height) as the mass touches the ground. The car continues to move with the speed last reached. This can be determined using the photoelectric gates and the timer.

From the given height the pupils should calculate the potential energy and plot it against v^2. The slope k (with the dimension of a mass) should be compared with the total mass m. This yields $m = 2\ k$. The formula $E_{kin} = 1/2\ m\ v^2$, which will be derived elsewhere, should be made plausible this way.

Note

- In order set the correct track inclination to compensate for friction, a second gate can be used: push the car with one hand, read the beam interruption time for the first gate, press "reset" before the car reaches the second gate, and compare the second beam interruption time with the first.
- With the 90 cm track no values can be obtained for 80 cm.

Material

Material from "TESS-Mechanik ME 1" (order nr. 13271.88), "TESS-Mechanik ME 2" (order nr. 13272.88) and "TESS-Mechanik ME 4" (order nr. 13283.88)

Position No.	Material	Order No.	Quantity
1	Measurement/experimental car	11060-00	1
2	Shade plate for the measurement car	11060-10	1
3	Holding pin	03949-00	1
4	Silk thread, 200 m	02412-00	1
5	Weight holder, bronzed, 1 g	02407-00	1
6	Slotted weight, bare, 1 g	03916-00	4
7	Slotted weight, black coloured, 10 g	02205-01	4
8	Slotted weight, black coloured, 50 g	02206-01	3
9	Pulley, movable, d = 40 mm, with hook	03970-00	1
10	Rod for pulley	02263-00	1
11	Timer 2-1, incl. power supply	13607-99	1
12	Compact photoelectric gate	11207-20	1
13	Foot plate for the compact photoelectric gate	11207-22	1
14	Connecting cable, red, 32 A, 1000 mm	07363-01	1
15	Connecting cable, yellow, 32 A, 1000 mm	07363-02	1
16	Connecting cable, blue, 32 A, 1000 mm	07363-04	1
17	Track 1, l = 500 mm	11302-00	1
18	Track 2, l = 500mm	11303-00	1

Material required for the experiment


17/18
11
12
9
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1
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16

Setup

Set up the track according to Fig. 1 + 2.

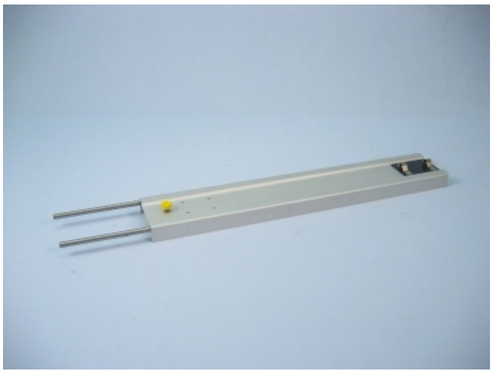


Fig. 1

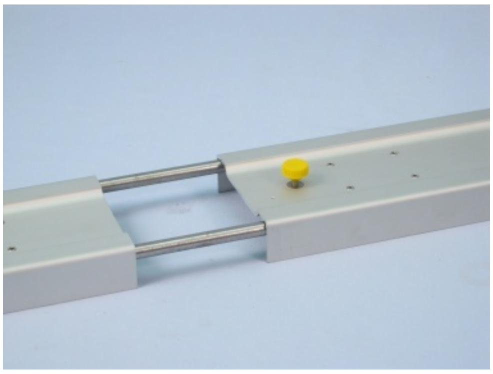


Fig. 2

Place the shade plate and two 50 g weights on the car's retaining bolt (Fig. 3) and set the inclination of the track so that the car continues to roll with a speed which is as continuous as possible once it has been pushed toward the end with the pulley (Fig. 4). To do this, place the screw on the other end of the track onto the notched weights and turn its adjustment screw (one 50 g and one 10 g weight should be about right).


Fig. 3

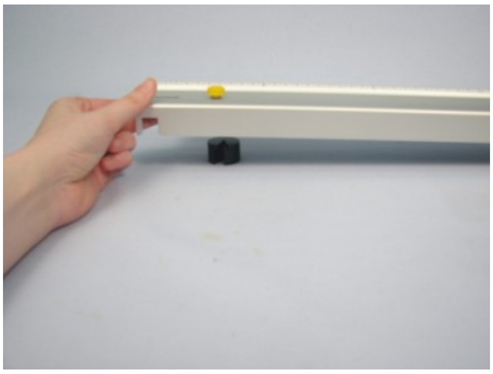


Fig. 4

Screw the foot plates onto the photoelectric gate (Fig. 5) and connect the gate to the timer (Fig. 6).

Fig. 5

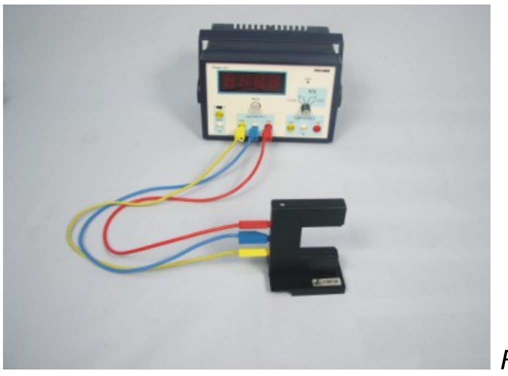


Fig. 6

Move the rotary switch to the "" position, the second from the left. Now the device will show the beam interruption time. That is the time during which the light beam in the gate is interrupted by the shade plate.

Put one end of the thread through the hole in the retaining bold on the underside of the car (Fig. 7), draw it under the car and onto the upper side and tie it to the retaining bolt (Fig. 8). Tie the other end to the 1g weight holder (Fig. 9), and choose the thread length so that the weight reaches the ground as the car reaches the last quarter of the track, more or less.

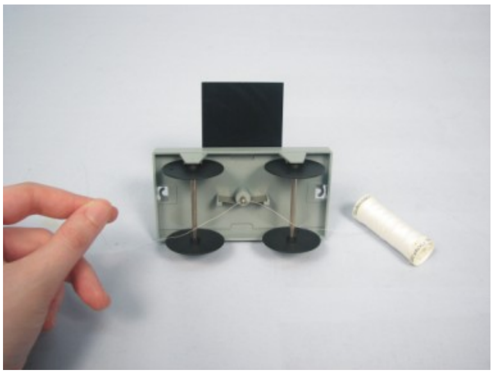


Fig. 7

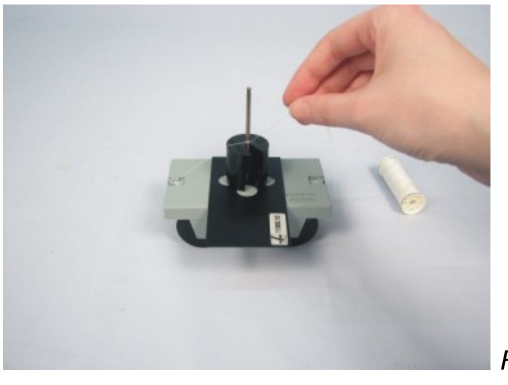


Fig. 8

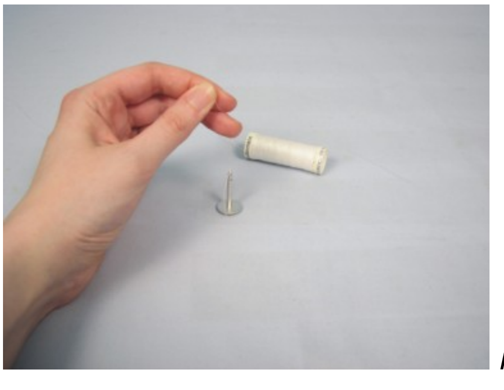


Fig. 9

Place a 10 g weight on the 1g weight holder, so that the weight pulling the car is 11 g (Fig. 10).

Fig. 10

Fix the pulley to the rod (Fig. 11) and clamp it on the track (Fig. 12). The thread should run over the car's axles, parallel to the surface of the track and over the pulley (Fig. 13).

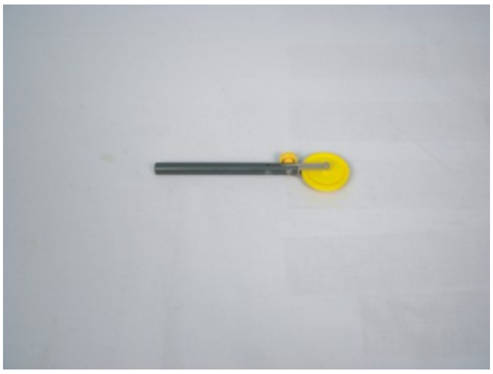


Fig. 11

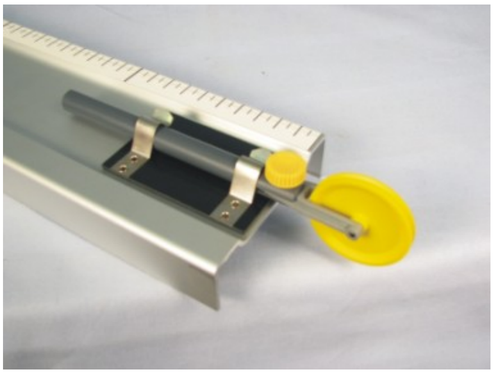


Fig. 12

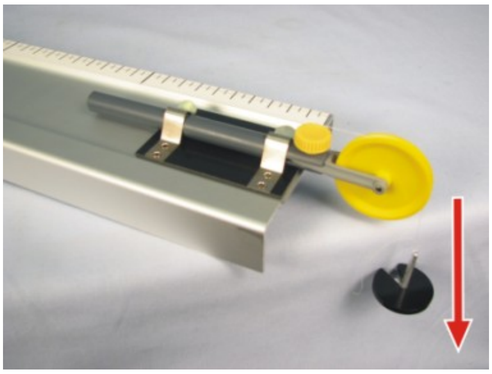


Fig. 13

Procedure

Take note of the position of the car as the weight touches the ground while retaining tension on the thread.

Place the gate so that its beam is interrupted by the plate as soon as the weight has touched the ground.

Push the car from this point a distance of s = 10 cm uphill. In doing this, the weight is lifted from the ground by the same distance, attaining the potential energy $E_{pot} = m_g \cdot g \cdot s$. At this point, s equals the height h of the weight with the mass m_g over the ground in the earth's gravitational field with the gravitational acceleration $g = 9{,}81\ m / s^2 = 9{,}81$ N / kg.

Before each measurement, press the timer's reset button.

Let go of the car and catch it after it has gone through the gate. Record the interruption time, t, displayed at the timer, on table 1. This is the time needed for the car to cover the distance Δs = 0.05 m, that is, the width of the plate.

Carry out several measurements, in which the distance s, by which the car is pushed uphill, is increased in 0.10 m increments.

If necessary, make the thread shorter by pulling on the thread on the upper side of the car and passing it around the hook at the end of the car and the retaining bolt.

Results

Table 1

h in m	Δt in s	$v_h = \Delta s / \Delta t$ in m/s	$E_{pot} = m_g \cdot g \cdot h$ in Nm	v_h^2 in m^2/s^2	m_{exp} in kg
0.10					
0.20					
0.30					
0.40					
0.50					
0.60					
0.70					
0.80					

Table 1

h in m	Δt in s	$v_h = \Delta s / \Delta t$ in m/s	$E_{pot} = m_g \cdot g \cdot h$ in Nm	v_h^2 in m^2/s^2	m_{exp} in kg
0.10	0.139	0.36	0.011	0.129	0.167
0.20	0.099	0.51	0.022	0.255	0.169
0.30	0.081	0.62	0.032	0.381	0.170
0.40	0.072	0.69	0.043	0.482	0.179
0.50	0.064	0.78	0.054	0.610	0.177
0.60	0.059	0.85	0.065	0.718	0.180
0.70	0.055	0.91	0.076	0.826	0.183
0.80	0.051	0.98	0.086	0.961	0.180

Evaluation

Question 1

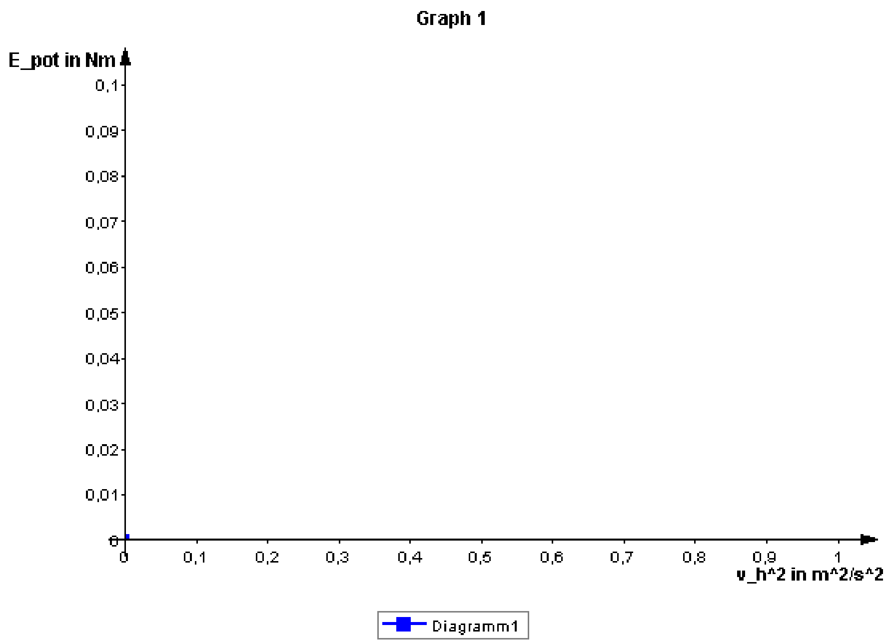
Calculate the instantaneous speed, v_h , after the weight has dropped along the height *h*, that is, the quotient of the plate width Δs = 0.05 m and the time Δt: $v_h = \Delta s/\Delta t$. Complete the table.

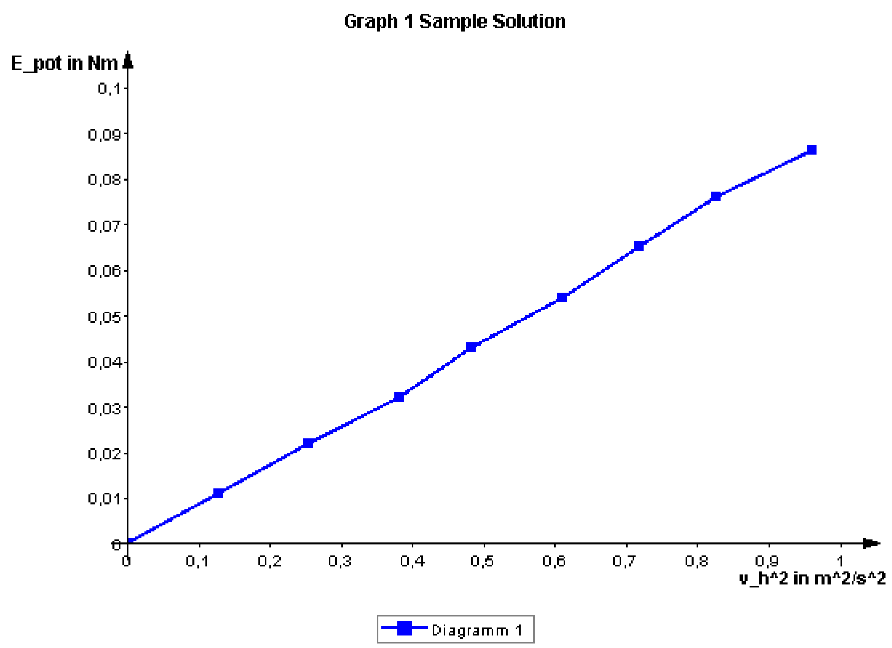
See table 1.

Question 2

Calculate the potential energy, $E_{pot} = m_g\ g\ h$, and complete the table.

See table 1.


Graph 1
E_pot in Nm
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
v_h^2 in m^2/s^2
Diagramm1


Graph 1 Sample Solution
E_pot in Nm
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
v_h^2 in m^2/s^2
Diagramm 1

Question 3

Calculate the square of the speed reached, v_h^2, complete the table. In Graph 1, E_{pot} was plotted against v_h^2. What kind of relation do you obtain?

Look at table 1 and graph 1. Kinetic energy appears to be proportional to the square of the speed.

Question 4

Determine the value of the total accelerated mass, $m = m_W + m_g$, and record it: m= ______ (car + retaining bolt 50 g, plate 10 g).

The total accelerated mass is $m = m_W + m_g = 170$ g.

Question 5

Determine the slope k for the curve in graph 1. What dimension or units does k have? Compare the result with the total accelerated mass $m = m_w + m_g$. What do you notice?

The physical quantity of the slope k is mass: [N m s^2 m^{-2}] = [kg m s^{-2} m s^2 m^{-2}] = [kg], and therefore the unit used is kg. Wit k = 0,092 kg this results in slightly more than half of the mass accelerated $m = m_w + m_g$.

Question 6

Assume that $E_{kin} = 1/2\ m\ v_h^2$ applies to the kinetic energy and that this is equal to the potiential energy, $E_{pot} = m_g\ g\ h$. Then, from the experiment a value, m_{exp}, can be calculated for the mass from the values in the fourth and fifth columns of table 1, according to $1/2\ m_{exp}\ v_h^2 = E_{pot}$, from which follows $m_{exp} = 2\ E_{pot} / v_h^2$. With this, complete the table and compare the values obtained with the values for the mass in question 4.

The value of the masses, m_{exp} , are similar to one another and the mass m = 170 g, however, they have the tendency to increase with increasing energy, E_{pot} . At this level of accuracy, the assumptions in the question are confirmed.

Question 7

The track was inclined in order to compensate for the car's friction. The car's potential energy was therefore drawn upon to overcome the force of friction. Consider what happens if the car's force of friction is dependent on its speed. Are there other sources of error?

In fact, there are friction forces acting upon the car which are speed-dependent, for example, wind resistance. Therefore, only one type of friction has been compensated. With increasing potential energy the loss is greater, and therefore the actual speed reached is lower and the value of the calculated mass, m_{exp} , is increased. In the case of this track, which is put together out of two separate parts, its unevenness is perhaps an error source which is not insignificant.