MODULE 14

DYNAMICS, WORK, AND ENERGY 2

1. GOALS

1.1. Determine the magnitude of energy change in the system.
1.2. Determine spring constants using the concept of energy

2. TOOLS AND MATERIALS

2.1. Rail (1 pc.)
2.2. Mini train (1 pc.)
2.3. Waterpass (1 pc.)
2.4. LabQuest Stream interface (1 pc.)
2.5. Computer with LoggerPro installed (1 set)
2.6. Photogate sensor system and its base (1 set)
2.7. Weight scale (1 pc.)
2.8. Ruler (1 pc.)
2.9. Loads (4 pcs.)
2.10. Lattice cover plate (1 pc.)
2.11. Round spring (1 pc.)

Figure 14. 1 Tools and Materials Used

3. BASIC THEORY

3.1. Dynamics and Newton's Law of Motion

Dynamics is a physical concept which explains the motion of a particular object along with its cause, in this case is a force working to the object. The principles of dynamics are based on the three Newton's law of motions.

Newton's First Law explains the case in which no force is given to the system or the total of force vector applied is zero. In this case, the system will not be accelerated and therefore tends to maintain its current state (moving at a constant velocity).

The concept was further generalized by Newton's Second Law. This law states that if a force ($\vec{F}$) works on a system at a particular direction, then the system will accelerate by $\vec{a}$ at the exact same direction. The ratio between the two values is given by the object's mass (m). Mathematically, this law can be written as:

$$\Sigma\vec{F} = m\vec{a} \tag{14.1}$$

Where $\Sigma\vec{F}$ is the force resultant, which is the vector sum of all forces applied to the system.

Lastly, Newton's Third Law states that an interaction between two systems will generate forces from both systems, one to each other, in an opposing direction. This law was more known as the action-reaction law. The formulation of Newton's Third Law is given as:

$$\vec{F}_{12} = -\vec{F}_{21} \tag{14.2}$$

Where $\vec{F}_{12}$ is the force exerted by system 1 to system 2, vice versa.

3.2. **Force**

There are varieties of force, each with its own characteristics. In this experiment, several forces that may be observed including spring force, gravitational force, normal force, and friction force.

Spring force is exerted by a spring of a constant k which is stretched or compressed by $\Delta\vec{x}$ from its equilibrium. To restore its state, the spring will generate a force of $\vec{F}_{spring}$ at an opposing direction of the displacement. This statement is expressed mathematically as:

$$\vec{F}_{spring} = -k\Delta\vec{x} \tag{14.3}$$

Gravitational force is done by the Earth to attract every object to the center of the Earth. The affected object will experience a gravitational acceleration ($\vec{g}$) which generates a force of $\vec{F}_g$ whose magnitude depends on the object's mass.

The mathematical formulation of gravitational force is given as follows:

$$\vec{F}_g = m\vec{g} \tag{14.4}$$

Normal force ($\vec{F}_N$) is generated by the interaction of a system and the surface it is placed on. The direction of normal force is always perpendicular to the surface. Its magnitude is exactly the same as the force exerted by the system at the direction perpendicular to the surface, up to the threshold point where the force given by the system will break the surface.

Friction force ($\vec{f}$) is generated by the interaction of the system and the surface where the system is moving. The force will resist the system's motion due to this force direction which is always opposing the direction of system's motion. The amount of interaction between the system and the surface is quantified by the friction coefficient (μ) which is then split further as coefficient of static friction (μ_s) and coefficient of kinetic friction (μ_k). Generally, the magnitude of friction force is given as follows:

$$f = \mu N \tag{14.5}$$

Where N is the magnitude of normal force. When a force of $\vec{F}$ is applied to the system, if $\vec{F} \leq \mu_s N$, the system will stay at rest. However, if the condition is surpassed, the system will experience motion with an affecting friction force of $f = \mu_k N$. The friction force will affect the system until it is back to rest.

3.3. **Free-Body Diagram**

A free body diagram is commonly used to figure all forces working to a system so that the force resultant can be calculated by vector operation. Furthermore, by the use of Newton's Second Law, the system's acceleration can also be calculated.

Free-body diagram analysis is commonly done by splitting each force to two directional components, x and y. The direction can be determined freely. However, the most common practice is to take the x-axis parallel to the surface observed and y-axis perpendicular to the surface in an attempt to simplify the analysis.

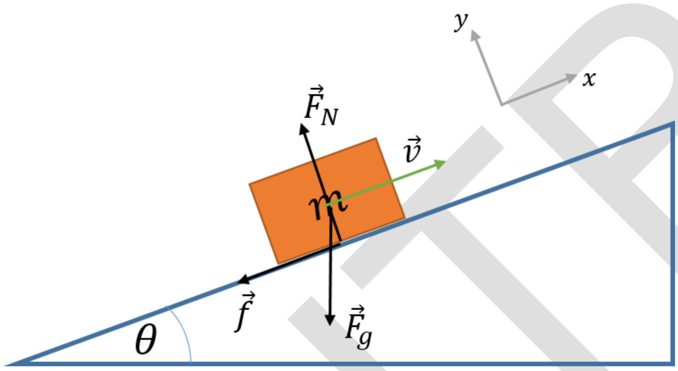

Figure 14.2. An example of free-body diagram on a rough inclined plane.

3.4. **Theorem of Work and Energy**

The concept of energy can be defined as work done by a certain amount of force. Work done by force $\vec{F}$ on a system that moves it as far as $d\vec{r}$ can be defined as $W_{\vec{F}} = \int \vec{F} \cdot d\vec{r}$. By mathematical derivation, an equation is obtained as follows:

$$W_{F_{total}} = \frac{1}{2} m (v_{final}^2 - v_{initial}^2) \qquad (14.6)$$

The kinetic energy of an object can be defined as $EK = \frac{1}{2} m v^2$ which means that work done by a certain amount of force on the object will alter the kinetic energy. The statement above is defined as:

$$W_{F_{total}} = \frac{1}{2} m (v_{final}^2 - v_{initial}^2) = \Delta EK \qquad (14.7)$$

The resultant of force working on an object or system consists of conservative force where the force doesn't rely on it's track, and non-conservative force where the force relies on it's track. Examples of conservative forces are gravitational force, Coulomb force, and spring force where the work only rely on the initial and final position. Examples of non-conservative forces are resistance and kinetic friction where work will be larger when the track followed is longer.

When an object receives energy from conservative force, that energy will be stored as potential energy. To demonstrate, an object affected by gravitational force will store potential energy because gravitational force is one example of conservative energy. The potential energy depends on the distance (position) of the object relative to the earth. One way to measure it is to assume that the ground is the basis.

Energy cannot be created or destroyed, by it can be changed from one form to another. Total work done consists of work done by conservative and non-conservative forces. Thus it can be stated that:

$$W = W_{nk} + W_k = \Delta EK \quad (14.8)$$

With W as total work, W_{nk} as non-conservative work, W_k as conservative work, and ΔEK as the change of kinetic energy.

In the experiment conducted, non-conservative work appears due to friction that is unable to be omitted. Conservative work can be defined as the change in the gravitational potential energy and/or spring potential energy of the object. With that being said, the theorem of work and energy may be written as:

$$W_g = -\Delta EP = \Delta EK \quad (14.9)$$

In which the change in gravitational potential energy is given by:

$$\Delta EP_g = mg\Delta h \quad (14.10)$$

And the spring potential energy is formulated as:

$$EP_{spring} = \frac{1}{2}k\Delta x^2 \quad (14.11)$$

From the theorem, the law of mechanical energy conservation can be defined where the change in kinetic energy will be the same as the change in potential energy of an object or system.

4. PRACTICE MATERIALS

4.1. Derive the work-energy theorem equations (14.8) and (14.9).
4.2. Derive the gravitational potential energy equation (14.10).
4.3. Derive the spring potential energy equation (14.11).

5. EXPERIMENTAL PROCEDURES

5.1. Experiment 1: Spring Potential Energy and Kinetic Energy

1. Measure the mass of mini train, lattice cover plate, and additional loads. Note the results in Table 14.1.

Table 9.1 Mass measurement.

Element	Mass [g]	Mass [kg]
Train		
Lattice cover board		
Additional Load 1 (M1)		
Additional Load 2 (M2)		
Additional Load 3 (M3)		
Additional Load 4 (M4)		

2. Install the rounded spring at one end of the rail and the photogate sensor at a distance of 0.5 m in front of the spring.

3. Install the lattice cover plate on the mini train as shown in Figure 14.3.
4. Adjust the configuration so that the rail is in a flat position, use a waterpass to check it. Also check by placing the train on the rails so that it doesn't experience movement on the rails.
5. Connect the photogate sensor to the first channel socket in LabQuest Stream.
6. Open the LoggerPro application in PC, ensure that the photogate sensor already detected by the program.

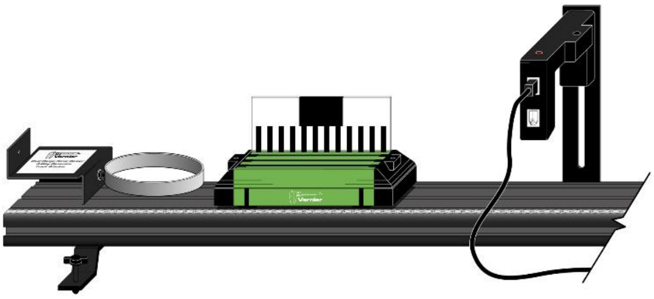

Figure 14.3. Experiment 1 apparatus scheme.

7. Click the ▶ Collect button to record the data. Adjust *photogate for Gate Timing*.
8. Move train forward past the photogate sensor. Make sure the Gate State reads Blocked when it is blocked by the black side of the lattice cover plate and Unblocked when it is not blocked and the measured distance is 0.05 m.
9. Press the rounded spring with the mini train until it retracts by 2 cm. Hold in that position.
10. Click the ▶ Collect button to start recording the data
11. Release the mini train, let it move past the photogate.
12. Note the velocity values at the 3rd, 4th, and 5th data as shown in the program. Write the results in Table 14.2.
13. Repeat steps 14-12 by varying the retraction of the spring, each to 3 cm and 4 cm.
14. Repeat steps 14-13 by increasing the load on the train by 5 data intakes.

Table 14.2 Experiment 1 data collection.

No.	Elements	Mass [kg]	Δx [m]	v_1 [m/s]	v_2 [m/s]	v_3 [m/s]	$\bar{v}$ [m/s]	Δx^2 [m^2]	ΔEK [J]
1	Train + Lattice		0.02						
			0.03						
			0.04						
2	Train + Lattice + M1		0.02						
			0.03						
			0.04						
3	Train + Lattice + M1 + M2		0.02						
			0.03						

			0.04						
4	Train + Lattice + M1 + M2 + M3		0.02						
			0.03						
			0.04						
5	Train + Lattice + M1 + M2 + M3 + M4		0.02						
			0.03						
			0.04						

15. Do a linear regression with Δx^2 as x-axis and ΔEK as y-axis for each mass variation. Also, draw each graph of ΔEK in respect to Δx^2 (there will be 5 graphs in total).
16. Determine the spring constant value from the gradient obtained by linear regression.

Table 14.3. Spring constant values obtained from Experiment 1.

Elements	Spring Constant [N/m]
Train + Lattice	
Train + Lattice + M1	
Train + Lattice + M1 + M2	
Train + Lattice + M1 + M2 + M3	
Train + Lattice + M1 + M2 + M3 + M4	

5.2. **Experiment 2: Spring Potential Energy and Gravitational Potential Energy**

1. Adjust the height of the two ends of the rail so that the end with the spring is in the low position and the other end is in the high position as in Figure 14.4.
2. Note the distance between the higher end of the train and the furthest end of the rail (zero point of the length scale on the rail) as $S_{initial}$. Measure as well the height of that initial point as $h_{initial}$.

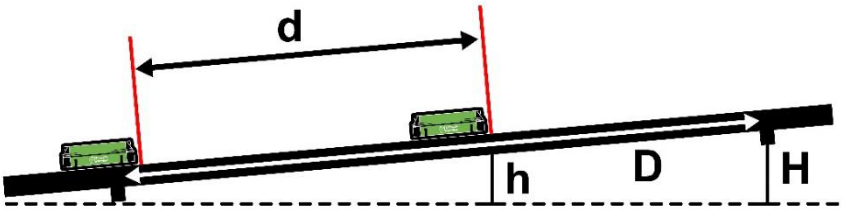

Figure 14.4 Experiment 2 apparatus scheme.

3. Press the rounded spring with the mini train until it retracts by 2 cm. Hold in that position.
4. Release the train, mark and record the position of the train when it stop before turning in the opposite direction. Note the value as S_{stop} and h_{stop} in Table 14.4.
5. Repeat steps 3-4 by increasing the load on the train by 5 data intakes.

Table 14.4 Experiment 02 data collection.

No	Element(s)	Mass [kg]	Δx [m]	S_{stop}		ΔS [m]	h_{stop}		Δh [m]	Δx^2 [m]	ΔEK [J]
				[cm]	[m]		[cm]	[m]			
1	Train		0.02								
			0.03								
			0.04								
2	Train + M1		0.02								
			0.03								
			0.04								
3	Train + M1 + M2		0.02								
			0.03								
			0.04								
4	Train + M1 + M2 + M3		0.02								
			0.03								
			0.04								
5	Train + M1 + M2 + M3 + M4		0.02								
			0.03								
			0.04								

$S_{initial}$ = ______ m $\qquad$ $h_{initial}$ = _______ m

6. Do a linear regression with Δx^2 as x-axis and ΔEP as y-axis for each mass variation. Also, draw each graph of ΔEP in respect to Δx^2 (there will be 5 graphs in total).
7. Determine the spring constant value from the gradient obtained by linear regression.

Table 14.5 Spring constant values obtained from Experiment 2.

Element(s)	**Spring Constant [N/m]**
Train	
Train + M1	
Train + M1 + M2	

Train + M1 + M2 + M3	
Train + M1 + M2 + M3 + M4	

6. ANALYSIS

6.1. Explain the changes in the form of energy that occur in this case. If work by friction is not neglected, what happens?

6.2. If there is a large enough friction, then how the graph will be obtained? Also mention the factors that influence the effect of friction on the data to be obtained!

6.3. Did the inclination angle of the rail in Experiment 2 affects the value of spring constant obtained? Explain for both conditions where friction is neglected and considered.

7. REFERENCES

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