Laboratory 4 Pre-Lab (value: *2 marks*)

Submit to your lab instructor ***by 4pm the day BEFORE*** your lab period.

1. How far does a projectile (initially at rest) fired *horizontally* at 5.0 m/s fall *vertically* in 2.0 s?

2. A spring ($k = 2.00 \times 10^2$ N/m) is compressed by 3.2 cm. How much PE is stored in the spring?

3. An object moves only *horizontally* in Earth's gravitational field; does $\vec{F}_g$ do *work* on it? Explain.

4. What are the SI units of *power*? Fundamentally, how is *power* different than *work*?

Laboratory 4: Energy, Work and Power

Experiments are to be completed on the provided laboratory sheets below; any supporting material (eg. graphs) should be attached. Make sure your name and your partners name(s) are clearly indicated on the front page of your lab. **Neatness and clarity count!** Explain your answers clearly and concisely. If an equation is to be used in a calculation, *write the equation down* and then insert numbers and solve. Report your final answer to the appropriate significant figures.

The lab write-up is due by the end of the lab. Late labs will not be accepted.

APPARATUS

2 Metre stick(s) & vertical stand, projectile launcher and C-clamp, eye protection, plum-bob, cork board, cardboard 'stop', bubble level, triple-beam balance, wooden ramp, metre stick, Ohaus 20 N spring scale, 1 kg hooked mass, stopwatch.

OBJECTIVE

1. To determine the maximum height of a projectile using the principle of energy conservation.
2. To determine the force required and work performed in moving a mass along different paths.
3. To determine the work performed and the power expended in climbing a flight of stairs.

THEORY

Projectile Motion and Mechanical Energy

For a projectile launched horizontally with an initial speed v_0, the horizontal distance that it travels is given by $x = v_0 t$, where t is the time that the projectile is in the air (friction with the air is assumed to be negligible.) The vertical distance, y, that the projectile falls in this time is given by $y = \frac{1}{2}gt^2$, where $g = 9.81$ m/s^2 is the acceleration due to gravity. The time of flight of the projectile is therefore given by

$$t = \sqrt{\frac{2y}{g}} \tag{1}$$

From the time of flight and the horizontal distance travelled, the initial velocity may be found by

$$v_0 = \frac{x}{t} \tag{2}$$

The initial kinetic energy of the projectile will be given by

$$KE_i = \frac{1}{2} m v_0^2 \tag{3}$$

where m is the mass of the projectile. The projectile launcher used in this lab consists of a spring which is compressed and then released, firing the projectile. The initial energy stored in the compressed spring is given by

$$PE_s = \frac{1}{2} k x_c^2 \tag{4}$$

where x_c is the amount of compression and k is the spring constant (a measure of how easily the spring can be compressed; it is typically expressed in newtons-per-meter or N/m).

If the launcher fires the projectile vertically, all of the energy stored in the spring will be transformed into gravitational potential energy of the projectile and so

$$PE_g = mgh = PE_s \tag{5}$$

where h is the total vertical height that the projectile has risen above its initial position.

Work and Power

The work, W_g, performed by gravity is given by

$$W_g = -\Delta PE = PE_{gi} - PE_{gf} \tag{6}$$

The work, W, performed by any individual force, F, acting over some distance, d, is given by

$$W = Fd \tag{7}$$

The power, P, expended by this same force over a time interval, Δt, is given by

$$P = \frac{W}{\Delta t} \tag{8}$$

Work is energy and is measured in joules (J); power is the rate at which work is done and is measured in joules-per-second (J/s) or watts (W).

NAME:
DATE: PARTNER:

Laboratory 4: Energy, Work and Power

Part A ** EYE PROTECTION MUST BE WORN DURING THIS PART **

1. Clamp the projectile launcher to the lab bench in its horizontal configuration (Figure 1).

2. Adjust the angle of the launcher to 0 degrees so that the ball will fire **horizontally**, away from the bench and onto the floor towards a nearby table leg. Load the steel ball into the launcher and use the provided black rod to 'push' it FULLY into to the **long-range position**. If the ball 'rolls' or 'shifts' while in the launcher and will NOT remain at the back of the barrel in contact with the spring, adjust the angle of the projectile launcher *slightly* upward, *i.e. 1-2 degrees*, until it does.

3. **Place the protective cardboard backing against the 'targeted' table leg and slide the cork board horizontally up against it** (Figure 2). Fire a few test shots to determine where the ball strikes the cork board. **Unclamp and adjust the horizontal location of the launcher so that shots consistently fall near the middle of the cork board**. Tighten the C-clamp and both of the angle adjustment screws on the launcher. Tape a piece of white paper to the cork board **with the short edge even with the end of the cork board closest to the launcher**.

Figure 1: Horizontal firing position


Figure 2: Cork board

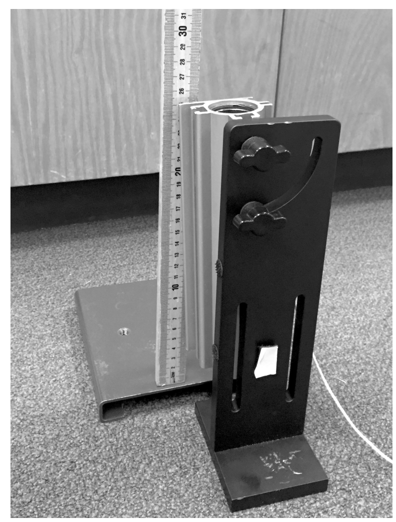
Figure 3: Vertical firing position

4. **Fire five (5) shots horizontally onto the paper** by pulling gently *upward* on the string attached to the firing mechanism. When the ball is fired and strikes the paper it will leave a slight divot/mark on the white paper and its position may be recorded. **Following each shot** mark the location of the center of the impact with a small dot or '+'. DO NOT MOVE the cork board or paper! The shots will likely NOT land exactly in the same position each time (*e.g. have some 'scatter'*) but they SHOULD be consistent, overall; IF any single shot is *significantly* different from the others, check that the C-clamp/angle adjustment screws on the launcher are tight & redo that trial.

5. [***1 mark***] Use the plumb bob to locate the point on the floor directly beneath the *MIDDLE of the launch position of the ball marked on the side of the barrel.* **Measure the horizontal distance along the floor from this point to the leading edge of the paper/cork board & record below as x_{base} (in cm)**. *Use proper measurement techniques & significant figures and show ALL work. ** NOTE ** x_{base} is longer than the two-metrestick so you will NEED to combine several rulers to measure it. DO NOT use the ends of the rulers and CLEARLY show how you combined ruler measurements in the space below.* **MAKE SURE to measure in cm and NOT inches!**

x_{base} = ________________.

6. [***1 mark***] **Measure the distance from the leading edge of the paper to each of the five impact dots** and record below. **Calculate the average impact distance** (in cm).

Shot	End position (cm)	Zero position (cm)	Calculated length (cm)
1			
2			
3			
4			
5			
		Average impact distance:	

7. [***1 mark***] **Calculate the average total horizontal distance** x_{tot} travelled by the ball by adding the value for x_{base} to the average impact distance (above); convert x_{tot} to meters:

x_{tot} = ________________ + ________________ = ________________ = ________________.

8. [***1 mark***] LEAVE the gun in horizontal mode. Move the cork board to the floor directly beneath the projectile launcher. **Measure (in cm) the total vertical distance** y_{tot} that the metal ball fell, from the *BOTTOM of the launch position of the ball marked on the side of the barrel* to the *TOP* of the cork board. **Convert to m**. *Show ALL work/steps/zero readings!*

y_{tot} = ________________.

9. [***1 mark***] **Measure the mass of the steel ball (in g)** and then convert to kg:

m_{ball} = ________________ = ________________.

**** Assume the gravitational acceleration to be $g = 9.81$ m/s^2 and to have 3 sig figs. ****

10. [***2 marks***] Use y_{tot} and Equation 1 to calculate the *time of flight* t; then use x_{tot}, t and Equation 2 to calculate the *initial (launch) velocity* v_0. **Check your calculated value of v_o with your instructor BEFORE proceeding further**. *Show ALL work.*

11. Place the two-metre stick in the vertical holder with numbers increasing *UPWARD* and the *cm-only side facing OUTWARD*. **Remove the projectile launcher from the lab bench & adjust the firing angle** so that it is *VERY slightly* less than 90°, *i.e. just off of vertical.* **Place the launcher on the floor** next to the vertical two-metre stick **as shown in Figure 3**.

12. [***1 mark***] Use the vertical two-metre stick to record the POSITION of the TOP of the launcher, h_i. Fire the ball on the long-range setting; adjust the launcher position & angle slightly so the high point of the ball's flight occurs IN FRONT of the meter stick. Record the max height h_f of the TOP of the metal ball after launch (to the nearest cm ONLY). Do 5 trials. For each trial calculate the height above the launcher, h. Finally, calculate the average height above the launcher, h_{avg}.

Shot	h_f (cm)	h_i (cm)	Calculated height h above launcher (cm)
1			
2			
3			
4			
5			
			h_{avg} = cm = m

13. [***1 mark***] **Calculate the ball's kinetic energy** (in *joules*) after launch using Equation 3.

14. [***1 mark***] *Energy cannot be created nor destroyed, only transformed from one form to another.* What fundamental principle of physics are we invoking with this statement? How does it apply to our situation of firing a ball vertically, i.e. *where does the initially stationary ball* 'get' *its kinetic energy from? Where does it* 'go'*?* What assumption(s) do we make in applying this principle?

15. [***1 mark***] Use PE_s (see above) and Equation 4 to calculate the *spring constant* k of the spring (in units of N/m). *NOTE: the spring is compressed by 0.074 m in the long range setting.*

**** Assume the gravitational acceleration to be $g = 9.81$ m/s^2 and to have 3 sig figs. ****

16. [***1 mark***] The height h of the ball above its initial unfired position (*in the launcher with the spring compressed*) is found using PE_s and Equation 5. The predicted height h_{pred} of the ball above the TOP of the launcher is found by *subtracting the compression of the spring* (*0.074 m*) FROM h. **Calculate** h **& then use it to find** h_{pred} **(in m)**. *Show ALL work & watch sig figs.*

$h_{pred} =$ ________________.

17. [***2 marks***] **Compare** h_{pred} to your measured height h_{avg} using *percent difference*. **Comment**.

18. Tidy the apparatus.

Part B

1. [***1 mark***] Use the spring scale to **measure the average force** required to lift the provided mass vertically from the floor to the top of the lab bench. Pull on the scale slowly at constant speed and *estimate the reading to the nearest 0.1 N*: $F_{avg} =$ ______________.

PROPERLY measure the vertical distance d, *showing ALL work*, (in cm). Convert to m.

2. [***1 mark***] Use Equation 7 to *calculate the work done* moving the mass with NO RAMP.

3. [***1 mark***] Place the wooden 'ramp' against the bench so that the top edge of the ramp is aligned with the top of the lab bench. Use the spring scale to **measure the average force** required to pull the provided mass *along the ramp* from the floor to the top of the table. Pull on the scale slowly at constant speed and *estimate the reading to the nearest 0.1 N*: $F_{avg} =$ ______________.

PROPERLY measure the length d of the ramp, *showing ALL work*, (in cm). Convert to m.

4. [***1 mark***] Use Equation 7 to *calculate the work done* moving the mass USING THE RAMP.

5. [***1 mark***] Which method (ramp or no ramp) required more work? Why? [*HINT: force(s)?*]

6. [***2 marks***] Use Equation 6 to calculate the work done ***by gravity*** in EACH case. Discuss.

7. [***1 mark***] Given your answers above, what is the benefit of the ramp? [*HINT: think Egyptian!*]

8. [***1 mark***] Using calculations of the work from parts 2 & 4 and your answers in 5 & 6, determine how much work is done ***by friction*** on the ramp. **What sign *should* this work be? Explain**.

Part C

1. [***1 mark***] Go outside and **determine the total *vertical* height of the staircase** between Starbucks & the Natural History Museum. *Detail your method & show ALL work/steps.*

2. [***1 mark***] **Measure the time** (to nearest second) to climb the stairs (both normally & 'fast').

3. [***1 mark***] **Calculate the (average) force exerted** during the climb. [1.00 lb = 4.45 N].

4. [***1 mark***] **Calculate the *work* done** climbing both normally & fast. **Discuss briefly**.

5. [***1 mark***] **Calculate the *power* exerted** climbing both normally & fast. **Discuss briefly**.