Name: **Index No:**

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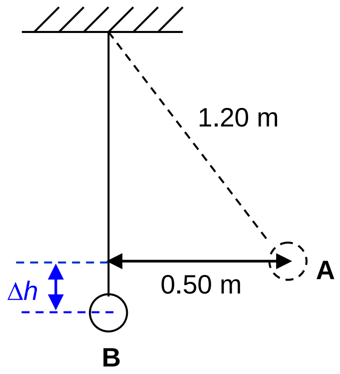
Assignment 05: Work, energy and power (IP)

For all the questions, take gravitational acceleration, g = 10 m s^{-2}.

1. A simple pendulum consists of a small bob of mass 0.050 kg suspended by an inextensible string. The length of the pendulum is 1.20 m. The bob is pulled aside for a horizontal distance of 0.50 m to position **A** as shown in the diagram below and released. Assume air resistance is negligible.



(a) Calculate the decrease in the gravitational potential energy of the bob as it moves from position **A** to position **B**. [3]

Δh = 1.20 - √(1.20^2 – 0.50^2) [1]
= 0.1091 m

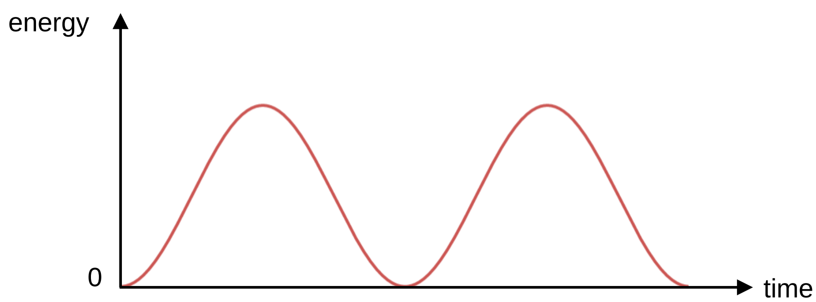
Decrease in G.P.E = (0.050 kg)(10 m s^{-2})(0.1091 m) [1]
= 0.055 J (to 2 s.f.) [1]

(b) Calculate the speed of the bob when it passes through position **B**. [2]

K.E.$_A$ + P.E.$_A$ = K.E.$_B$ + P.E.$_B$ OR Increase in K.E. = Decrease in G.P.E.

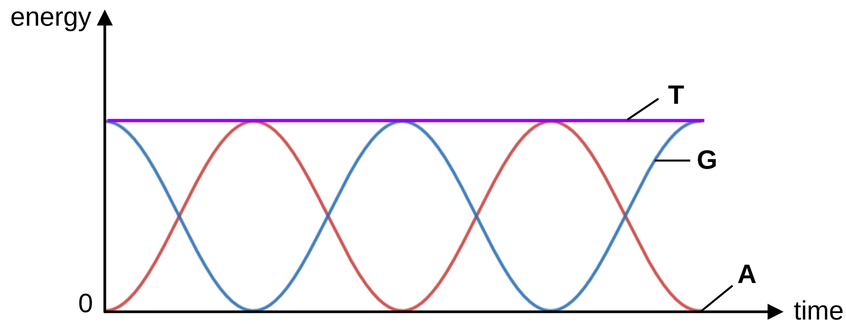
0 + 0.05455 J = ½ mv^2 + 0 [Assume reference level at B.]
½ (0.050 kg) v^2 = 0.05455 J [1]
v = 1.5 m s^{-1} (to 2 s.f.) [1]

(c) The diagram below shows the variation of the **kinetic energy** of the pendulum with time.



(i) Indicate, on the kinetic energy-time graph, the first instant when the bob returns to position **A** after it had been released. Label this point **A**. [1]

(ii) Draw, on the above diagram,
a. the corresponding variation of the gravitational potential energy of the pendulum with time and label it **G**,
b. the total energy of the pendulum with time and label it **T**. [2]



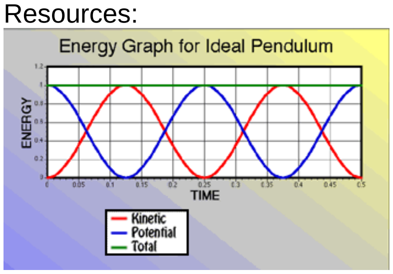
Reference: https://serpmedia.org/scigen/e1.3.html

(d) Consider the pendulum bob and the earth as the system. Explain the graph **G** you had drawn in (c)(ii). [2]

As the pendulum bob swings down, energy from the gravitational potential store is transferred to the kinetic store and vice versa as it swings up. [1]

At any point in time, the sum of energy in the gravitational potential store and the kinetic store is constant. [1]

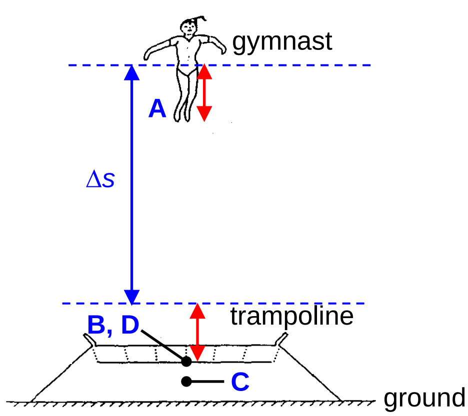
Resources:



Sinusoidal nature of pendulum motion:
https://www.physicsclassroom.com/class/waves/lesson-0/pendulum-motion
https://www.desmos.com/calculator

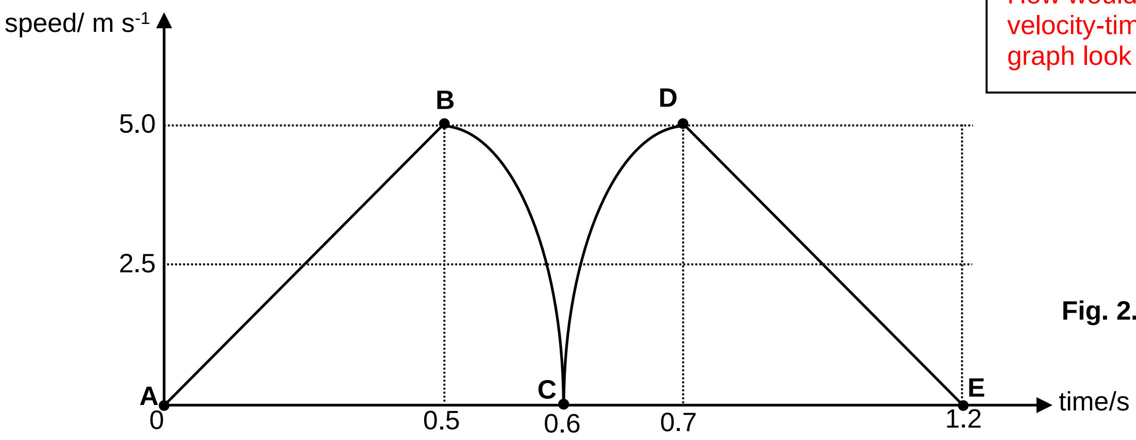
Animation:
https://www.myphysicslab.com/pendulum/pendulum-en.html

2. Fig 2.1 shows a gymnast jumping on a trampoline. Fig 2.2 shows the variation of her speed with time during her jump. The mass of the gymnast is 48.0 kg. Ignore the effects of air resistance.



Δ*s*: vertical displacement of gymnast's CG

Fig. 2.1



How would its velocity-time graph look like?

Fig. 2.2

(a) The points **A**, **B**, **C**, **D** and **E** on Fig. 2.2 indicate the various positions of the gymnast during her motion.

(i) At which position(s) did the gymnast achieve the maximum gravitational potential energy? [2]

At positions A [1] and E. [1]

(ii) At which position(s) did the gymnast cause the trampoline to achieve the maximum elastic potential energy? [1]

At position C. [1]

(b) From Fig. 2.2, determine

(i) the maximum kinetic energy of the gymnast, [2]

Maximum K.E. = ½ (48.0 kg)(5.0 m s^{-1})^2 [1]
= 600 J (to 2 s.f.) [1]

(ii) the maximum vertical change in displacement of the gymnast after she loses contact with the trampoline. Leave your answer to 2 significant figures. [2]

Maximum Δs = area under **DE** of *v*-*t* graph
= ½ (1.2 – 0.7)(5.0) [1]
= 1.25 m
= 1.3 m (to 2 s.f.) [1]

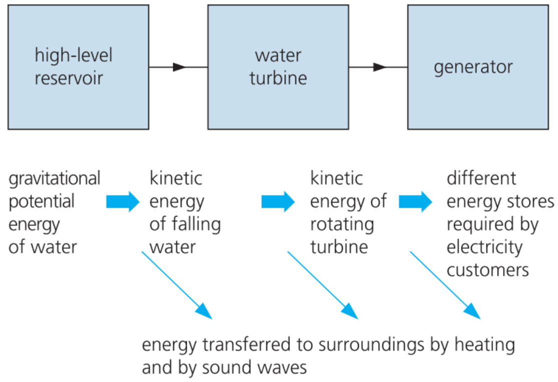
(c) (i) The change in gravitational potential energy of the gymnast when she first touches the trampoline to the lowest point of her jump is 192 J. Calculate the average power developed by the trampoline. Leave your answer to 2 significant figures. [2]

Average power developed = energy transferred / time taken
= (600 J + 192 J) / 0.1 s [1]
= 7.9 kW (to 2 s.f.) [1]

(ii) Describe the useful energy changes in ~~of~~ the system ~~gymnast~~ between the position when she first touches the trampoline to the lowest point in her jump. Consider the gymnast, the trampoline and the ground as the system. [1]

Energy in gravitational potential store and kinetic store of gymnast is transferred to elastic store of trampoline. (This is **B** to **C** on the graph.)

3. The diagram below shows the energy transfers in a small hydroelectric power station of 55% efficiency.



Source: Cambridge O Level Physics, Heather Kennett, Tom Duncan

The hydroelectric power station is used for one hour. During the hour, the level of water in the upper lake falls by 0.050 m. The area of the upper lake is 5.0×10^3 m^2 and it is 80.0 m above the turbine. No additional water enters the lake.

Calculate

(a) the mass of water which leaves the lake in one hour, (density of water = 1.0×10^3 kg m^{-3}) [2]

density = mass / volume

mass = $(1.0 \times 10^3$ kg m$^{-3})(5.0 \times 10^3$ m$^2)(0.050$ m$)$ [1]

= 250 000 kg (to 2 s.f.) [1]

(b) the decrease in the gravitational potential energy of the water which leaves the lake in one hour given that, on average, the water falls 80.0 m, [2]

decrease in G.P.E. = (250 000 kg)(10 m s^{-2})(80.0 m) [1]

= 2.0×10^8 J (to 2 s.f.) [1]

(c) the useful energy output of the power station in one hour, [2]

efficiency = (useful energy output / total energy input) x 100

55 = [useful energy energy / (2.0×10^8 J)] x 100 [1]

useful energy output = 1.1×10^8 J (to 2 s.f.) [1]

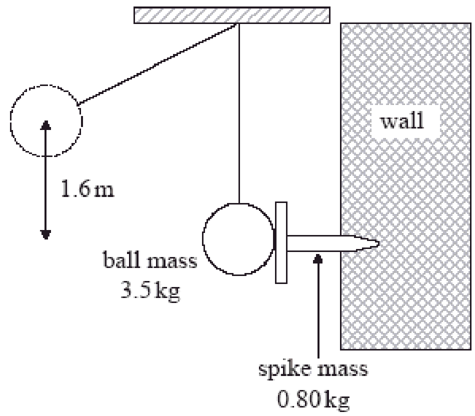
(d) the average electrical power produced by the generator during the hour. [2]

average electrical power = 1.1×10^8 J / 3600 s [1]

= 31 kW (to 2 s.f.) [1]

*Students should draw a diagram to visualize the problem.

4. A large swinging ball is used to drive a horizontal iron spike into a vertical wall. The centre of the ball falls through a vertical height of 1.6 m before striking the spike in the position as shown in the diagram.



(a) The mass of the ball is 3.5 kg and the mass of the spike is 0.80 kg. Immediately after striking the spike, the ball and spike move together.

(i) Show that the speed of the ball, on striking the spike, is 5.7 m s^{-1}. [1]

$v = \sqrt{(2 \times 10 \times 1.6)}$ [1]
$= \underline{5.7 \text{ m s}^{-1}}$ (shown)

(ii) Calculate the energy dissipated as a result of the collision, if the ball and the spike move together at 4.6 m s^{-1}, after the inelastic collision. [2]

K.E. before collision = ½ [3.5 × 5.657^2] (also equals G.P.E. at start = 56 J)

K.E. after collision = ½ [(3.5 + 0.80) × 4.6^2] [1]

Energy dissipated = 56.0 – 45.5 = <u>11 J</u> (to 2 s.f.) [1]

(b) As a result of the ball striking the spike, the spike is driven a distance 7.3 × 10^{-2} m into the wall. Calculate the magnitude of the constant net force F acting on the spike. [3]

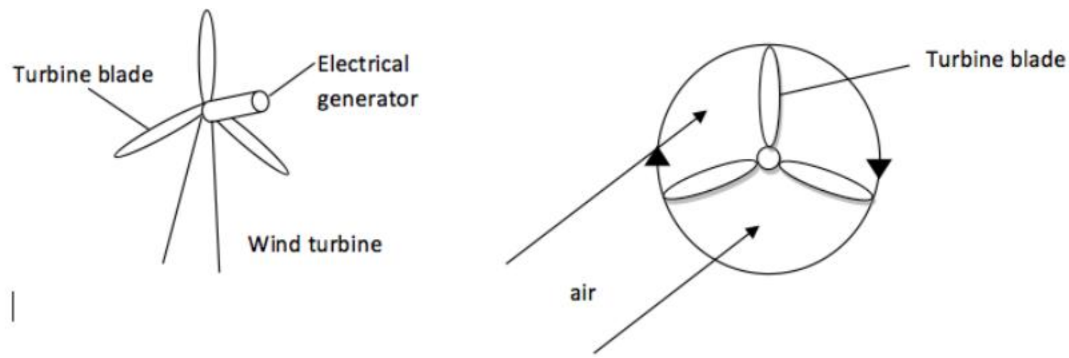
Method 1: Using concept of work	Method 2: Using equations of motion
W_{net} by F on spike = K.E.$_{final}$ – K.E.$_{initial}$ = 0 J – 45.5 J = - 45.5 J F_{net} (Δs) = - 45.5 J [1] F_{net} = - 45.5 J / (7.3 X 10^{-2} m) [1] = - 620 N (to 2 s.f.) Magnitude of F = <u>620 N</u> [1]	For the spike, u = 4.6 m s^{-1}, v = 0 m s^{-1}; $a = [- (u^2 / 2(\Delta s)]$ = [- 4.6^2 / 2(7.3 X 10^{-2})] [1] = - 144.9 m s^{-2} $F_{net} = ma$ = (3.5 + 0.8) × (-144.9) [1] = - 620 N (to 2 s.f.) Magnitude of F = <u>620 N</u> [1]

(c) The machine that is used to raise the ball has a useful average power output of 18 W. Calculate how long it takes for the machine to raise the ball through a height of 1.6 m. [2]

time taken = work done / average power

= (3.5 kg)(10 m s^{-2})(1.6 m) / 18 W [1]
= <u>3.1 s</u> (to 2 s.f.) [1]

5. In a remote part of Arizona, people build their own wind turbine to have at least a little electricity. The blades of the wind turbine are designed to curve slightly so that more wind can be captured. The diagram below shows a typical wind turbine that is connected to an electrical generator.



(a) (i) Briefly explain how the energy transfer is achieved in the wind turbine to generate electrical power. [2]

The energy in the ………kinetic………………… store of the wind is transferred ………mechanically………………… to the ………kinetic………………… store of the rotor blades of the wind turbines. Electrical power is generated when the rotor blades connected to the generators ………rotate/spin/turn………………….

(ii) An engineer is asked to redesign the wind turbine so that it can generate more electricity. Suggest **one** way where he can achieve his task. [1]

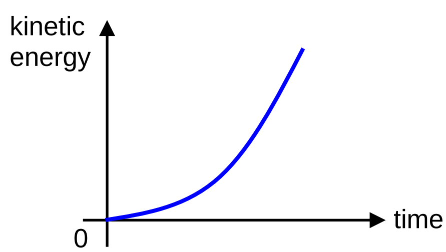
Increase number of turbine blades.
Increase surface area of turbine blades. [Reject: Make blades lighter.]

(b) On a windy day, the blades are able to sweep out a circle in 50 s, as shown in the diagram. Presuming that the mass of air is 6.0 x 10^5 kg on a windy day and travelling at a speed of 9.0 m s^{-1}.

(i) Calculate the initial energy in the kinetic store of this mass of air. [2]

$E_k = \frac{1}{2} mv^2$ $= \frac{1}{2}(6.0 \times 10^5 \text{ kg})(9.0 \text{ m s}^{-1})^2$ [1]
$= 2.43 \times 10^7$ J
$= 2.4 \times 10^7$ J (to 2 s.f.) [1]

(ii) Assuming that the speed of wind blades increases at a constant rate, sketch a graph of **kinetic energy against time** for the wind blades which was initially at rest. [1]



(c) This part question is about a 2.5 MW General Electric Wind Turbine.

Below is the specification of this wind turbine.

Output power rating / kW	2500
Minimum (cut-in) wind speed / m s^{-1}	3
Maximum (cut-out) wind speed / m s^{-1}	25
Rated wind speed / m s^{-1}	12.5
Number of blades	3
Rotor diameter / m	100
Sweep area / m^2	7854
Tower height / m	75, 85, 100

source: http://www.gepower.com

Assuming that the Wind Turbine is 62% efficient, calculate

(i) the power input by the wind on the wind turbine, [2]

2.5 MW = 0.62 Power input [1]
Power input = 4.0323 MW
= 4.0 MW (to 2 s.f.) [1]

(ii) the force exerted by the wind on each blade. [2]

Power = Force x velocity
4.0323 MW = Force (12.5 m s^{-1}) [1]

Force on each blade = 322 584 N / 3
= 110 kN (to 2 s.f.) [1]

The cut-in speed is the minimum wind speed at which the turbine starts generating electricity from turning.

The cut-out speed is the maximum wind speed the turbine can withstand without being damaged.

The rated peak speed is the wind speed at which the turbine returns the optimal amount of power. Wind speeds, both lower and higher than this speed, are likely to produce less energy.