DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

IB PHYSICS

LSN 2-3: WORK, ENERGY AND POWER

Questions From Reading Activity?

Essential Idea:

- The fundamental concept of energy lays the basis upon which much of science is built.

Nature Of Science:

- Theories:
  - Many phenomena can be fundamentally understood through application of the theory of conservation of energy.
  - Over time, scientists have utilized this theory both to explain natural phenomena and, more importantly, to predict the outcome of previously unknown interactions.
  - The concept of energy has evolved as a result of recognition of the relationship between mass and energy.

Theory Of Knowledge:

- To what extent is scientific knowledge based on fundamental concepts such as energy?
- What happens to scientific knowledge when our understanding of such fundamental concepts changes or evolves?

Understandings:

- Kinetic energy
- Gravitational potential energy
- Elastic potential energy
- Work done as energy transfer
- Power as rate of energy transfer
- Principle of conservation of energy
- Efficiency

Applications And Skills:

- Discussing the conservation of total energy within energy transformations
- Sketching and interpreting force–distance graphs
- Determining work done including cases where a resistive force acts
- Solving problems involving power
- Quantitatively describing efficiency in energy transfers

Guidance:

- Cases where the line of action of the force and the displacement are not parallel should be considered
- Examples should include force–distance graphs for variable forces

Data Booklet Reference:

$$W = Fs\cos\theta$$

$$E_k = \frac{1}{2}mv^2$$

$$E_p = \frac{1}{2}kx^2$$

$$E_p = mg\Delta h$$

$$power = Fv$$

$$Efficiency = \frac{useful\_work\_out}{total\_work\_in}$$

$$Efficiency = \frac{useful\_power\_out}{total\_power\_in}$$

Utilization:

- Energy is also covered in other group 4 subjects (for example, see: Biology topics 2, 4 and 8; Chemistry topics 5, 15, and C; Sports, exercise and health science topics 3, A.2, C.3 and D.3; Environmental systems and societies topics 1, 2, and 3)

Utilization:

- Energy conversions are essential for electrical energy generation (see Physics topic 5 and sub-topic 8.1)
- Energy changes occurring in simple harmonic motion (see Physics sub-topics 4.1 and 9.1)

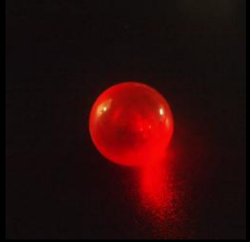
Aims:

- Aim 6: experiments could include (but are not limited to): relationship of kinetic and gravitational potential energy for a falling mass; power and efficiency of mechanical objects; comparison of different situations involving elastic potential energy

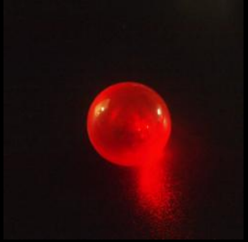
Aims:

- Aim 8: by linking this sub-topic with topic 8, students should be aware of the importance of efficiency and its impact of conserving the fuel used for energy production.

HERE IT COMES



GOALS AND SCALES



IB PHYSICS 1, UNIT 2: *MECHANICS*

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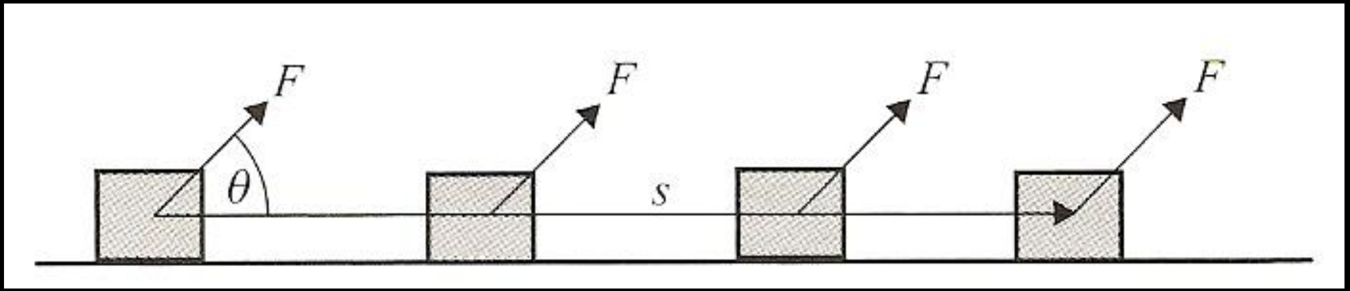
Introductory Video: Work

Work done by a force



- The work, W, done by a force, F, is shown by:

$$W = Fs\cos\theta$$

  - Where θ is the angle between the force and the direction of movement
  - Because *cos* θ can be positive, negative, or zero, work can be positive, negative, or zero

Work done by a force

$$W = Fs\cos\theta$$

- *Work is equal to the force times the distance moved by the object in the direction of the force.*
- This applies for a *constant force*
- If the force is not constant, we must graph force vs. distance and take the area under the curve to be the work done
- The unit for work is the Joule: 1J = 1 Nm

Work done by a spring

- The tension (or force) applied to a spring is given by T = kx, where k is the spring constant and x is the distance the spring is extended or compressed
- The greater the extension or compression, the more tension, or more force required

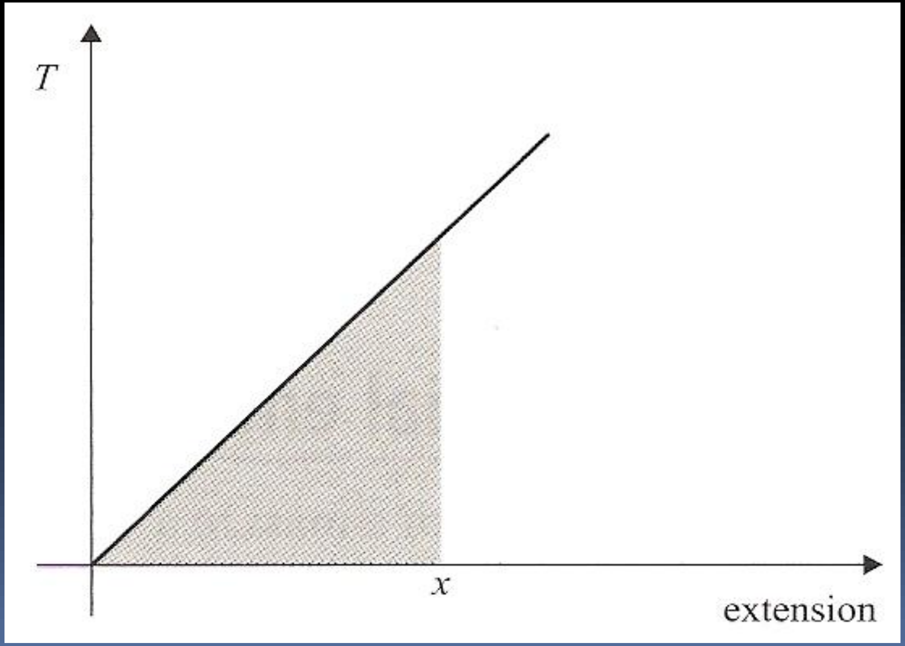
Work done by a spring

- If we graph force (tension, T = kx) vs. distance extended or compressed, we get the graph below
  - The area under the line is work
  - Since it is a triangle, the area is

$$W = \frac{1}{2}bh$$

$$W = \frac{1}{2}x(kx)$$

$$W = \frac{1}{2}kx^2$$



Work done by a spring

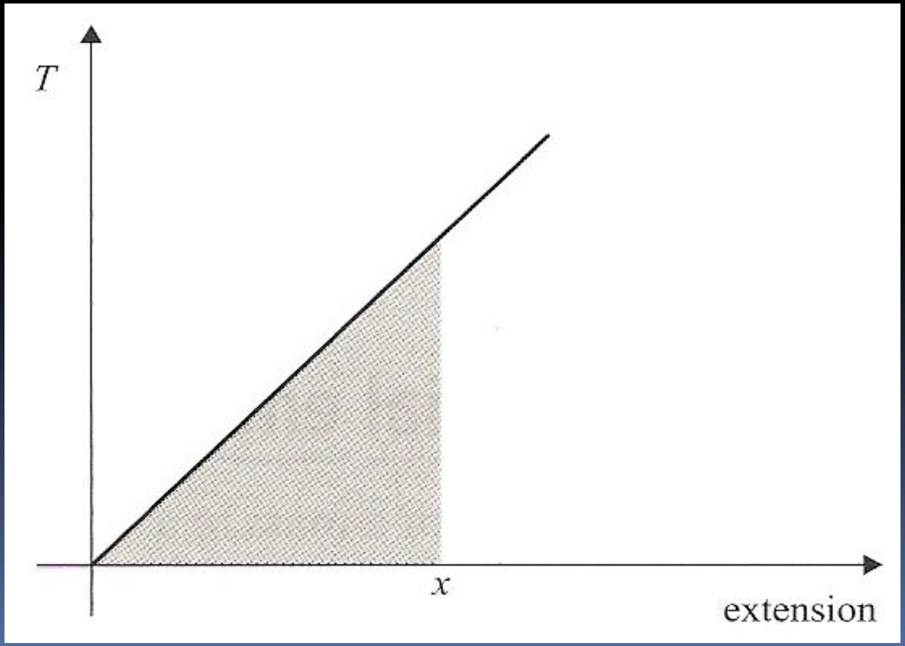
- ***Look familiar?***

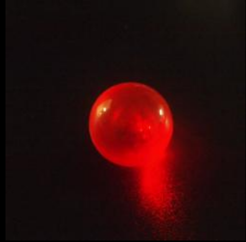
$$F = kx$$

$$E = \frac{1}{2}kx^2$$

$$W = \frac{1}{2}kx^2$$

$$W = E$$





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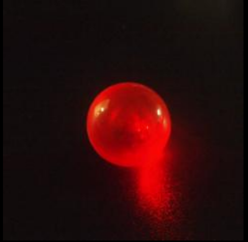

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Work done by gravity

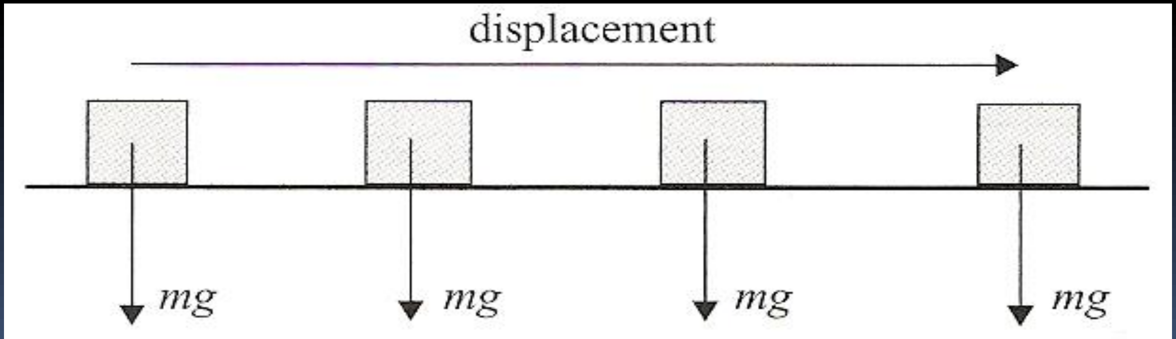
- Force is equal to mass times acceleration (F = ma), and weight is mass times acceleration due to gravity (mg), so weight (mg) is a force that always acts vertically because gravity acts vertically

Work done by gravity

- *When movement is horizontal, work due to gravity is zero. Why is this so?*

Work done by gravity

- *When movement is horizontal, work due to gravity is zero. Why is this so?*
  - If a mass is moved horizontally, the work done by gravity is zero because the angle between horizontal and vertical is 90° and cosine of 90° is zero



$$W = Fs\cos\theta$$

$$W = mgs\cos 90$$

$$W = 0$$

Work done by gravity

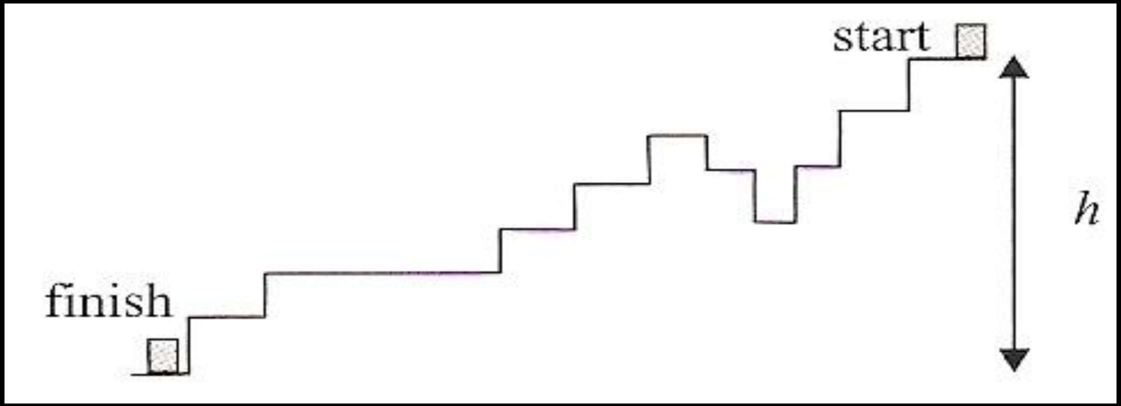
- If movement is in the vertical direction (displacement s = height h), the work done by gravity is equal to $\pm mgh$ since the movement is parallel to the force ($\theta = 0$) and $\cos 0° = 1$
- *When is the work due to gravity positive, and when is it negative?*

Work done by gravity

- *When is the work due to gravity positive, and when is it negative?*
  - If the movement is downward, work is ***+mgh*** because force is in same direction as movement
  - If the movement is upward, work is ***-mgh*** because force is in opposite direction of movement

Work done by gravity

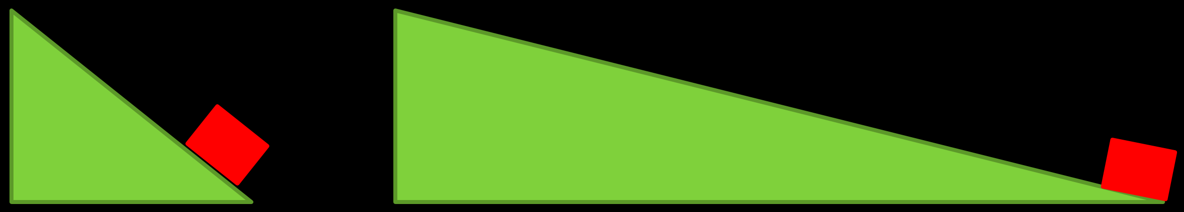
- Regardless of the path taken, the work done by gravity is always *mgh* where *h* is the net change in height (vertical displacement)



- Gravity does no work during horizontal movement, and since any downward movement is cancelled by an equal upward movement, total work (net work) is equal to *mgh*

Work done by gravity

- *In the diagram below, if the ramps were frictionless, would I do more work pushing a box up the short ramp to the left, or up the long ramp to the right?*



Work done by gravity

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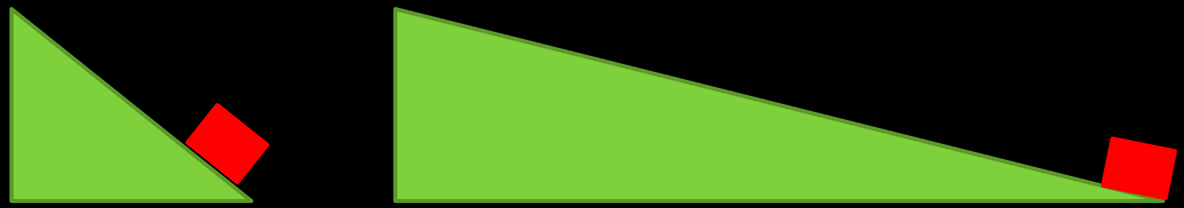
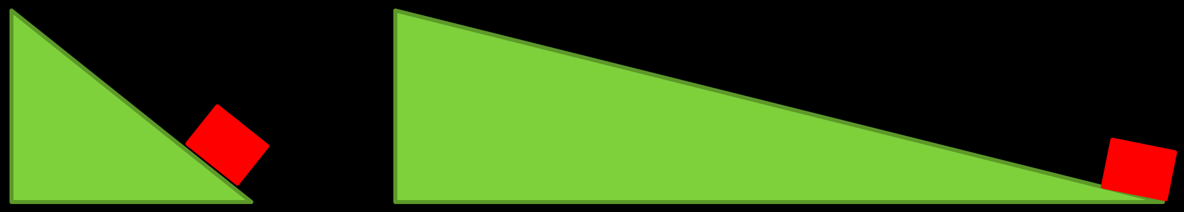


- If the net change in height is the same, the work *due to gravity* is the same
- However, it may take more ***power***

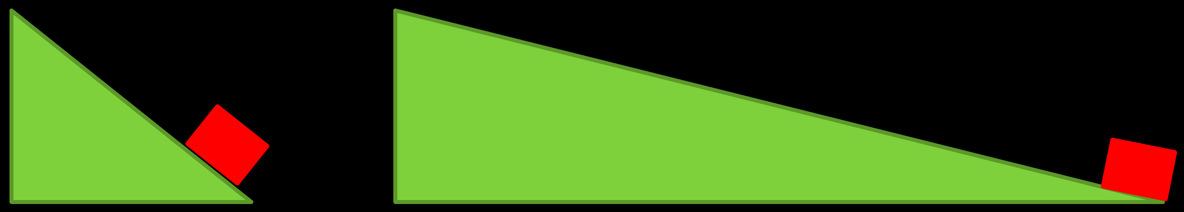
Work done by gravity

- *In the diagram below, if the ramps* ***were not frictionless****, would I do more work pushing a box up the short ramp to the left, or up the long ramp to the right?*



Work done by gravity

- *In the diagram below, if the ramps* ***were not frictionless****, would I do more work pushing a box up the short ramp to the left, or up the long ramp to the right?*



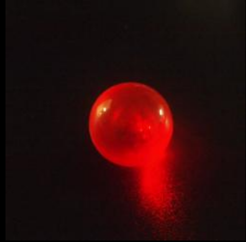
- *Since W = Fs, the work done by friction is greater on the ramp to the left*

Work done in holding something still

- *If I asked you to hold your 5kg textbook in your right hand with your arm fully extended for 5 minutes, how much work would you have to do?*

Work done in holding something still

- *If I asked you to hold your 5kg textbook in your right hand with your arm fully extended for 5 minutes, how much work would you have to do?*
  - Even though your arm would get really tired, you would do no work on the book because there is no net movement
  - You would expend a lot of *energy*, but you would do no *work*



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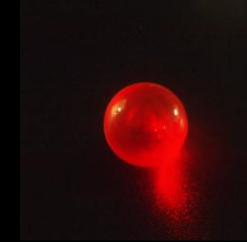

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Energy

Potential Energy

- Potential energy is the ability or *potential* to do work
- Think of it as stored work waiting to be used

Gravitational potential energy

- Work is force applied over a distance
- *If I lift a brick 1m above the ground, hold it there, then drop it, what work is done and by whom or what?*

Gravitational potential energy

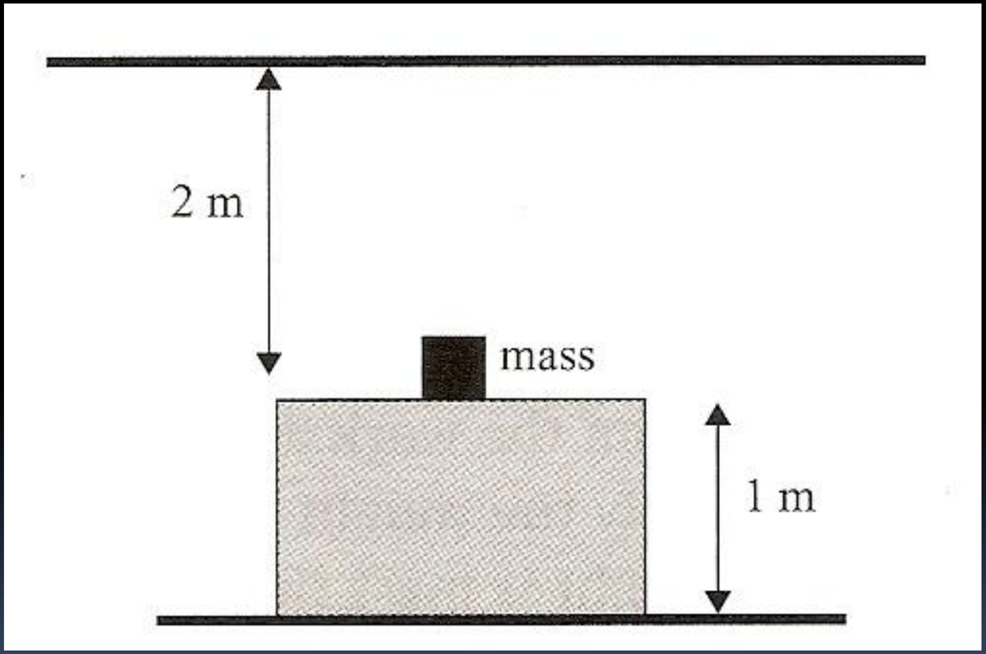
- *If I lift a brick 1m above the ground, hold it there, then drop it, what work is done and by whom or what?*
  - We do work on a brick by lifting it 1m above the ground equal to *mgh*
  - If we let go of the brick, gravity will do work on the brick equal to *mgh*

Gravitational potential energy

- *If I lift a brick 1m above the ground, hold it there, then drop it, what work is done and by whom or what?*
  - While the brick is held up in the air, the brick has the *potential* to do work equal to *mgh*, but does not do any work because there is no movement
  - The *potential to do work* is what is called *potential energy*, or in this case, <u>*gravitational potential energy*</u>
  - The amount of potential energy an object has is dependent on your frame of reference

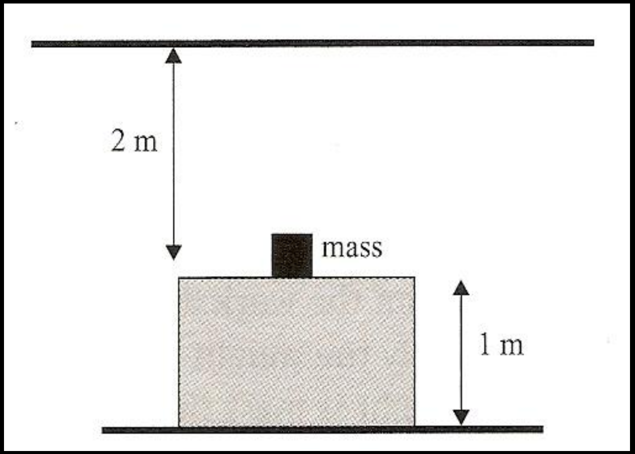
Gravitational potential energy

- *What is the potential energy of the 10 kg mass below?*



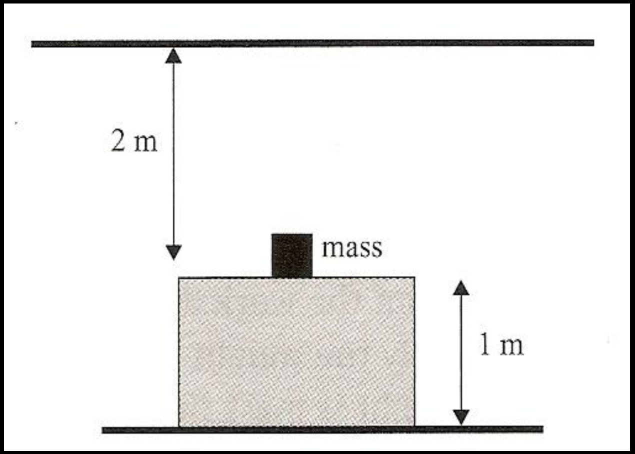
Gravitational potential energy

- *What is the potential energy of the 10 kg mass below (g = 10 m/s²)?*
  - If your reference is the floor, the mass has a potential energy of 100J
  - If your reference is the table, the mass has a potential energy of 0 since h is zero



Gravitational potential energy

- *What is the potential energy of the 10 kg mass below ($g = 10\ m/s^2$)?*
- If your reference is the ceiling, the mass has a potential energy of -200J because the reference is in the opposite direction of the force of gravity
- Therefore, any given mass can have different potential energies depending on the reference used



Elastic Potential Energy

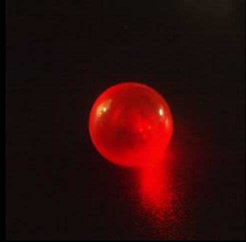
- *How much work is required to extend a spring a distance x?*

Elastic Potential Energy

- *How much work is required to extend a spring a distance x?*
  - The work required is equal to $\boldsymbol{W = 1/2kx^2}$ where k is the spring constant for the given spring
  - If the spring is held in the extended position, the work done has been stored in the spring as *elastic potential energy* equal to $\boldsymbol{E_p = 1/2kx^2}$

Potential Energy

- *When an external force changes the state of a system without acceleration and does work W in the process, the work so performed is stored as potential energy in the new state of the system.*



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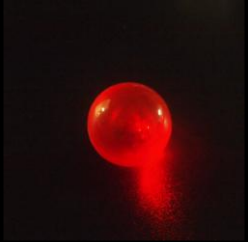

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Work-Kinetic Energy Relation

- From earlier lessons we learned that when a single force acts on a mass, it produces an acceleration

$$F = ma$$

- and that acceleration is equal to

$$a = \frac{F}{m}$$

Work-Kinetic Energy Relation

- *Let's say that a mass moving at a constant velocity is acted upon by a force. That force causes the mass to accelerate to a new, higher velocity. What work has been done? How is energy involved?*

Work-Kinetic Energy Relation

- ***Let's say that a mass moving at a constant velocity is acted upon by a force. That force causes the mass to accelerate to a new, higher velocity. What work has been done? How is energy involved?***
  - From kinematics we know
  - If we substitute *a* = *F/m* in to this equation, we get

$$v^2 = u^2 + 2as$$

$$v^2 = u^2 + 2\frac{F}{m}s$$

$$v^2 - u^2 = \frac{2Fs}{m}$$

$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$$

Work-Kinetic Energy Relation

- ***Let's say that a mass moving at a constant velocity is acted upon by a force. That force causes the mass to accelerate to a new, higher velocity. What work has been done? How is energy involved?***

- We know that *Fs* is work, and this shows that it is equal to a change in $1/2mv^2$
- The quantity $1/2mv^2$ is energy
- In the same way work equates to a change in potential energy, work can equate to a change in the energy of motion called kinetic energy

$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$$

$$E_k = \frac{1}{2}mv^2$$

$$W = \Delta E_k$$

Work-Kinetic Energy Relation

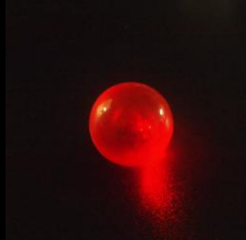
- ***Let's say that a mass moving at a constant velocity is acted upon by a force. That force causes the mass to accelerate to a new, higher velocity. What work has been done? How is energy involved?***

- The work done by a net force acting on a body is equal to the change in kinetic energy of that body.

$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$$

$$E_k = \frac{1}{2}mv^2$$

$$W = \Delta E_k$$



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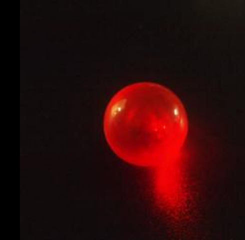

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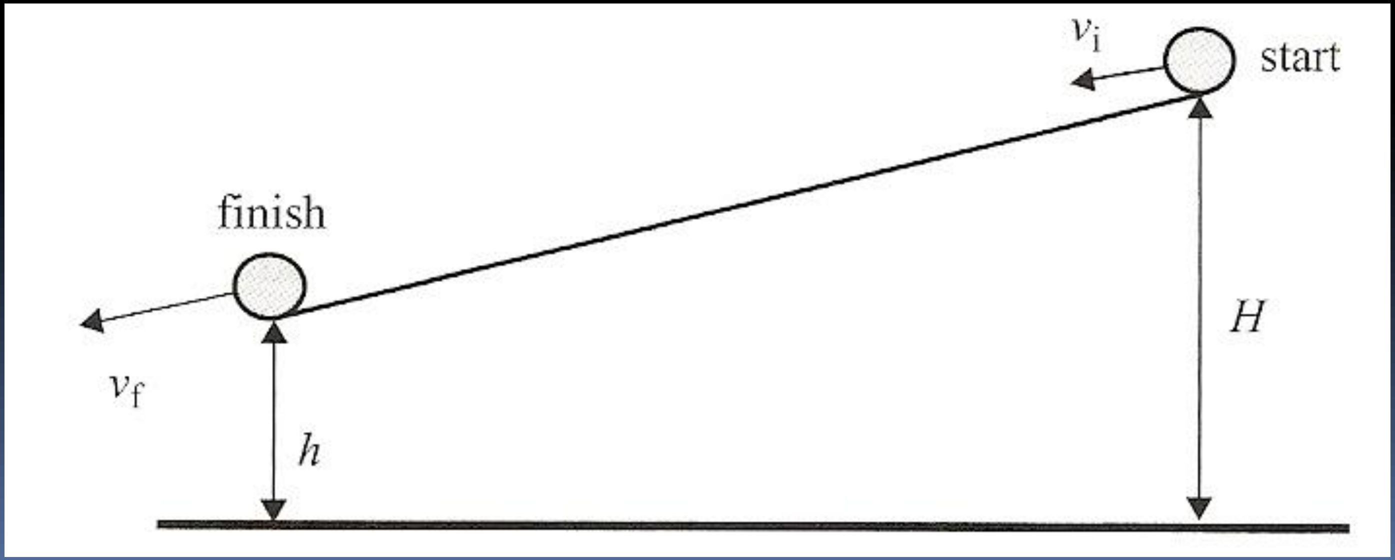
Conservation Of Energy

- Suppose that you have a ball at the top of an incline and the only force acting on it is gravity.
- *What will happen?*



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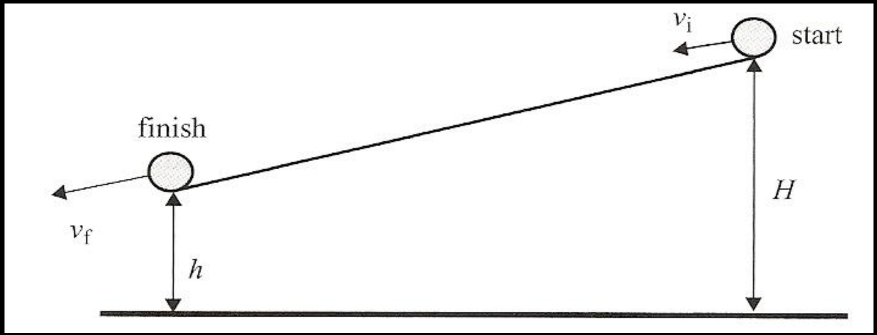


  - *The ball will roll down hill*
  - *It will accelerate and velocity will increase*
  - *Gravity will do positive work on the ball*
  - *Potential energy lost, kinetic energy gained*

Conservation Of Energy

- *What work is done by the normal/reaction force in this problem? Why?*

Conservation Of Energy

- *What work is done by the normal/reaction force in this problem? Why?*
  - None
  - The normal/reaction force is normal (duh) to the direction of motion, $W = Fs\cos\theta$

Conservation Of Energy

- The work done by gravity is W = mg(H-h), and work is equal to the change in kinetic energy W = 1/2mv^2 - 1/2mu^2, so our equation becomes,

$$W = mg(H - h)$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

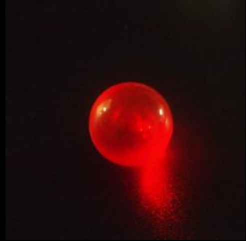
$$mg(H - h) = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

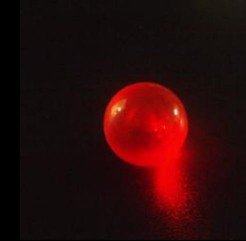
$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mu^2 + mgH$$

Conservation Of Energy

- What we find here is that the sum of the potential and kinetic energies at the top of the incline is the same as the sum of the energies at the bottom – *energy is conserved*
- We know from experience that the ball will speed up and we now know that potential energy decreases with decreases in height
- Therefore, some of the potential energy at the top of the incline converted to kinetic energy at the bottom of the incline

$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mu^2 + mgH$$





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Frictional forces

- Potential energy and kinetic energy are called ***mechanical energies*** and are caused by ***conservative forces***
- When *frictional or other external forces* (***nonconservative*** forces) are present, *total energy will still be conserved*, but *mechanical energy will not*

Frictional forces

- In this case we can write,

$$W = \Delta E$$

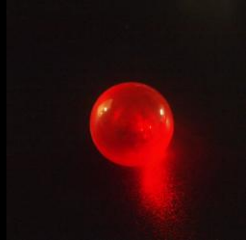
- where W equals total work done by the external forces and ΔE is the change in the mechanical energy of the system

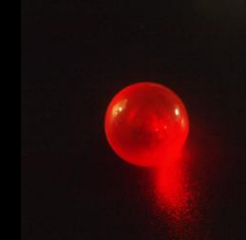
$$\frac{1}{2}mu^2 + mgh_1 = \frac{1}{2}mu^2 + mgh_2 + E_{NC}$$

Frictional forces

- The total energy does not change, but some of the mechanical energy has been transformed into another form of energy such as;
  - thermal energy (heat)
  - sound
  - electricity
- Within a system, total energy remains constant.
- Energy cannot be created or destroyed, but merely transformed from one form to another.

$$\frac{1}{2}mu^2 + mgh_1 = \frac{1}{2}mu^2 + mgh_2 + E_{NC}$$





GOALS AND SCALES
IB PHYSICS 1, UNIT 2: *MECHANICS*

4.0 □ I know the concepts listed below so well I can ***evaluate*** (make judgments based on evidence) presented or obtained data to determine their compliance and/or relevance to these concepts.
- □ Motion
- □ Forces
- □ Work, Energy and Power

3.0 □ I can ***analyze*** the concepts listed below using key elements and use these elements to ***apply*** the knowledge to solve problems.
- □ Motion
- □ Forces
- □ Work, Energy and Power

2.0 □ I can ***explain*** the concepts listed below in detail with both reasons and causes.
- □ Motion
- □ Forces
- □ Work, Energy and Power

1.0 □ I can ***describe*** the concepts listed below in detail.
- □ Motion
- □ Forces
- □ Work, Energy and Power

0.0 □ I do not get it.

Power

Power

- Not only is it important to know how much work is being done, but also how fast the work is being done
- Power is the rate at which work is being performed
- The unit for power is the watt (W) and one watt is equal to one joule per second, 1W = 1J/s

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

Power

- Remembering that work is defined as force times distance,

$$P = Fv$$

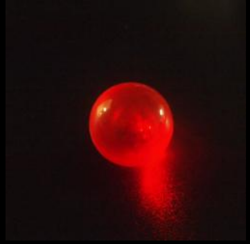
which applies when *v* is the instantaneous or constant velocity of the mass

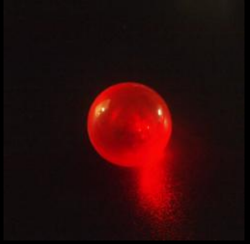
$$P = \frac{\Delta W}{\Delta t}$$

$$W = Fs$$

$$P = \frac{F \Delta s}{\Delta t}$$

$$P = Fv$$





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- □ Forces
- □ Work, Energy and Power

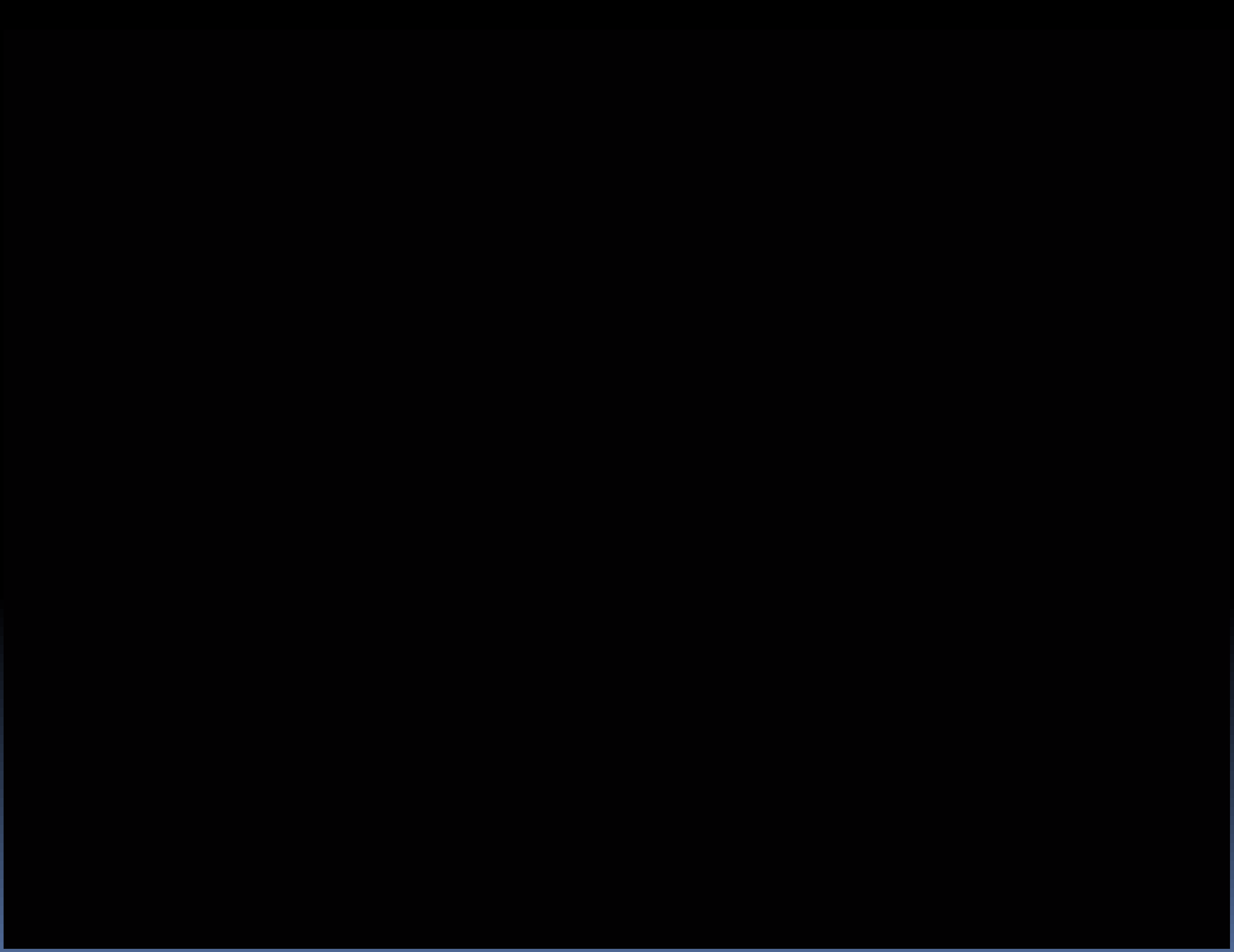
0.0 □ I do not get it.

Efficiency

- Because of those nasty non-conservative forces that pervade our society, not all energy is transformed into useful work
- Efficiency gives us the fractional or percent work done/energy out per unit work/energy input
- Also applies to power since power is a function of work

$$Efficiency = \frac{useful\_work\_out}{total\_work\_in} = \frac{useful\_power\_out}{total\_power\_in}$$

Summary Video: What is Energy



Applications And Skills:

- Discussing the conservation of total energy within energy transformations
- Sketching and interpreting force–distance graphs
- Determining work done including cases where a resistive force acts
- Solving problems involving power
- Quantitatively describing efficiency in energy transfers

Understandings:

- Kinetic energy
- Gravitational potential energy
- Elastic potential energy
- Work done as energy transfer
- Power as rate of energy transfer
- Principle of conservation of energy
- Efficiency

Data Booklet Reference:

$$W = Fs\cos\theta$$

$$E_k = \frac{1}{2}mv^2$$

$$E_p = \frac{1}{2}kx^2$$

$$E_p = mg\Delta h$$

$$power = Fv$$

$$Efficiency = \frac{useful\_work\_out}{total\_work\_in}$$

$$Efficiency = \frac{useful\_power\_out}{total\_power\_in}$$

Essential Idea:

- The fundamental concept of energy lays the basis upon which much of science is built.

QUESTIONS?

Homework

Pg. 96-97, #55-71