Arvind Borde / PHY 11, Week 6: Energy

We've been studying mechanics, a subject usually divided into ______________

(1) What's that?

____

and ______________

(2) What's that?

____

1

An equation such as ______________ is kinematical. It does not look into what might produce the force $\vec{F}$; it only concerns itself with how things move (accelerate) once there is a force $\vec{F}$, however it might originate.

Similarly, the equations of motion we've been using for constant acceleration are also kinematical.

2

______________ **A**

______________ **B**

______________ **C**

x_0, v_0: initial position, velocity;
a: (constant) acceleration;
t: time; and
x, v: position, velocity at (later) time t.

3

On the other hand, the law of gravitation,

is dynamical. It tells you what *causes* this force, gravitational, to arise. It says, among other things, that mass is the "source" of gravitation.

It also says how the force changes with distance.

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Other dynamical laws you'll study later will tell you that charge is the source of electric forces, "poles" the source of magnetic forces, etc.

At this point in the history of physics, we believe that there are just four fundamental forces, and we think we understand a lot about them.

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These are the fundamental forces and this is what they do:

- ______________________________
- ______________________________
- ______________________________
  ____
- ______________________________
  ____

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ADDITIONAL NOTES

Although we think we understand the fundamental forces, understanding how things behave from the fundamentals is difficult, and often impossible.

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The collision of two billiard balls is an example of electromagnetic forces at work. But it's impossible to understand how the balls might ricochet off each other, the angles they may move at after collision, etc., by analyzing the electromagnetic forces between the molecules of the two balls.

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Consider another question: sending a rocket to the moon.

The rocket sets off with some velocity in the direction of the moon.
(3) As it moves upward will it slow down or speed up (assuming it uses no further propulsion)?

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(4) What would happen if it were to slow to a stop (again no further propulsion)?

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(5) When would it be safe for the rocket to slow to a stop?

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(6) If the moon-earth distance is $\sim 3.8 \times 10^8$ m, can you calculate what the initial speed should be for it to get there with zero velocity at the end?

____

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(7) But that would be so wrong. Why?

____

11 ______________________________________

In order to figure out this question you have to solve

$$G\frac{M_{\text{earth}}m}{d_{\text{earth}}^2} - G\frac{M_{\text{moon}}m}{d_{\text{moon}}^2} = ma$$

where m is the mass of the rocket. Here, d_{earth}, d_{moon}, and a all vary with time.

Not easy to analyze via forces.

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ADDITIONAL NOTES

Enter ____________

This is an abstract concept – you can't see it, taste it, touch it, feel it, but it's important.

There are many forms of energy:

- Kinetic (due to motion)
- Potential (due to force)
- Heat

and so forth, *each with its own formula.*

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(8) Why is energy important?

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For example, the behavior of objects undergoing elastic collisions can be figured out using energies, *without detailed information on the forces involved.*

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If we find that energy does not seem to be conserved, we invent a new form of energy so that the total of old and new energy is still fixed.

When a ball drops, its kinetic energy changes as it picks up speed. We invent gravitational potential energy to keep the total energy fixed.

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The SI unit of energy is the ___________

It's equivalent, as we'll see, to

$$\frac{1\,\text{kg}\cdot 1\,\text{m}^2}{1\,\text{s}^2}$$

That's the same as $1\,\text{N}\cdot 1\,\text{m}$.

(9) Why? ______________________

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Kinetic Energy

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A mass m traveling at speed v has KE given by

(10) Correct units? ___________

(11) What's the KE of an $80\,\text{kg}$ physics professor moving at $.5\,\text{m/s}$?

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Gravitational Potential Energy

Close to the earth, an object of mass m at a height h from some reference level (usually the earth), has a gravitational PE given by

(12) Correct units? ___________

(13) What is the PE of a $50\,\text{g}$ physics student on a ladder that's $3\,\text{m}$ high?

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ADDITIONAL NOTES

(14) You kick a ball straight up at $5\,\text{m/s}$. How high does it go? Use eqn. **C**.

Now, eqn. **C** can be re-written as

$$v^2 = v_0^2 - 2g(y - y_0) = v_0^2 - 2gy + 2gy_0$$

or

$$v^2 + 2gy = v_0^2 + 2gy_0$$

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(15) Divide both sides by 2 and multiply by the mass m. What equation do you get and how do you interpret it?

.

____

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The formula for KE, ________ works everywhere.

The formula for grav. PE, _____, works close to earth. If you move far, the exact formula for the grav. PE between objects of masses m and M is:

where r is the distance between the centers of the two objects.

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This is used, for example, to calculate the escape velocity of a rocket ship from earth.

Let's say a rocket is launched from the surface of the earth. What would the minimum launch speed, v_{rocket}, have to be for the rocket to escape infinitely far?

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Initial total energy:

$$\frac{1}{2} m_{\text{rocket}} v_{\text{rocket}}^2 - G\frac{m_{\text{rocket}} M_{\text{E}}}{R_{\text{E}}}$$

Final total energy (rocket rests infinitely far):

$$\frac{1}{2} m_{\text{rocket}} 0^2 - G\frac{m_{\text{rocket}} M_{\text{E}}}{\text{“}\infty\text{”}} = 0$$

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Conservation of energy says

Initial total energy $=$ Final total energy

So, $$\frac{1}{2} m_{\text{rocket}} v_{\text{rocket}}^2 - G\frac{m_{\text{rocket}} M_{\text{E}}}{R_{\text{E}}} = 0$$

Or, $$\frac{1}{2} m_{\text{rocket}} v_{\text{rocket}}^2 = G\frac{m_{\text{rocket}} M_{\text{E}}}{R_{\text{E}}}$$

Canceling m_{rocket} from both sides, we get

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ADDITIONAL NOTES

or, multiplying by 2:

and, taking the square root:

25 "Escape velocity" for rockets from earth.

(16) With $= 6.67 \times 10^{-11}$ N·m^2/kg^2, $R_E = 6.4 \times 10^6$ m, $M_E = 6 \times 10^{24}$ kg, calculate the escape velocity $v = v_{\text{rocket}}$ from earth.

$v^2 =$

$v \approx$

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Spring Potential Energy

where x is the amount the spring is either stretched or compressed by from its natural length.

Note: k, the spring constant, has units of N/m.

(17) Why?

27 ______________________________

(18) If a spring has $k = 5$ N/m, how much energy is stored in it if it's compressed by 7 mm?

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(19) If a spring with $k = 8$ N/m is stretched by 3 cm, what is the maximum speed it can impart to an object of mass 100 g?

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Work

where F is the force applied, d the distance an object is moved by this force, and θ the angle between the displacement and the force.

(20) What are the units of work? __________

29 (21) Why? ______________________________

Work in physics is a technical concept, different from the day-to-day sense of "'work."

(22) What is the work done by you if you pull a block of mass 10 kg horizontally for 50 m using a force of 3 N at an angle of $60°$ with the horizontal?

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ADDITIONAL NOTES

Power

Power is the rate of doing work.

The unit is the Watt (1J/sec).

Since work is a form of energy, power can also be viewed as the rate of emission or absorption of energy. A 100 W light bulb, for example, emits 100 J of energy every second.

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ADDITIONAL NOTES