

Physics Problem Checklist

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This is a checklist for solving mechanics problems involving moving objects with mechanical energy and momentum and possibly under the influences of forces. It will not be useful for more simple kinematics problems, where you are told something about an objects motion (position, velocity, acceleration, etc.) and asked to figure out something else about its motion. It won't be useful for thermodynamics problems, either. The checklist also doesn't describe how to solve force-body diagram problems (i.e. Newton's laws problems), which focus on one point in time and ask you find the magnitude of some force or acceleration.

Checklist

This should help you figure out how to solve a problem. If at any point during this checklist you find that you have already solved the problem, don't bother continuing on with the rest of the checklist.

1. Identify the objects in the system
2. Identity the different time events in the problem
3. Identity where energy is stored at each time event
4. See if you can figure out the work (Eq. 1) done on the system during each time interval:
 - If the work is zero, then mechanical energy is conserved (Eq. 2)
 - If there is non-zero work, then use the work-energy theorem (Eq. 3)
 - If you can't figure it out easily, then this is a dead end
5. Identity where momentum is stored at each time event
6. See if you can figure out the impulse (Eq. 4) done on the system during each time interval:
 - If the impulse is zero, then momentum is conserved (Eq. 5)
 - If there is non-zero impulse, then use the impulse-momentum theorem (Eq. 6)
 - If you can't figure it out easily, then this is a dead end
7. If this checklist has not yet led you to the solution, then this problem might take a little bit more creativity.

1 The system

A problem will give you a situation in which several objects exert forces on each other. It is your job to decide which of these objects should be part of the "system" and which should be external. Generally, the objects that belong in the system are "movable" objects while the ones that belong

outside the system are the fixed background objects. If you prefer, the objects in the system are the actors and the objects outside of the system are the stage.

Belong inside the system:

- Anything that is free to move and has mass, pretty much. Often square blocks.

Belong outside the system:

- The earth, *unless* you use gravitational potential energy
- Springs attached to the floor/walls, *unless* you use elastic potential energy
- The floor, walls, ceiling, inclined planes, which can exert normal forces or frictional forces
- People who might be pulling or pushing objects of their own free will

2 Time events

Often a problem can be made a lot simpler by considering it to consist of a sequence of time of several simpler problems. These events could be

- an initial, intermediate final point in time that the word problem mentions
- collisions, during which mechanical energy can be lost
- an object moving from one place with certain forces to another place with different forces
- a person deciding to hit, throw, or otherwise exert a force on something
- something getting turned on or off

3 Energy

There is a total amount of energy in the universe that is always conserved. However, when you study a particular system of objects energy can flow into this system or out of the system if external forces do work (positive or negative) on the system. Furthermore, some of the energy of the objects in the system can be converted into "jittering" of the material at a microscopic level. We call this microscopic-level **thermal energy** (since it has to do with temperature) and call the macroscopic-level energy **mechanical energy**. If you look at a system you can "see" the mechanical energy in the motion and position of the objects; you can only "see" the internal energy if you have a thermometer. Mechanical energy is divided into **kinetic energy** of motion and **potential energy**. There are certain special types of external forces which can take away energy from an object but always "give it back" when the object returns to the same location. So, we can pretend that this isn't an external force at all (see the *unless*s above) but is a part of the system that stores potential energy. Then the total mechanical energy of the system is constant, but it can shift between kinetic energy and potential energy.

Types of energy:

- Kinetic energy $KE = \frac{1}{2}mv^2$
- Gravitational potential $U_g = mgh$, where h is the relative height to a reference point

- Elastic potential $U_s = \frac{1}{2}k\Delta l^2$, where Δl is the change of spring length with respect to its normal state
- Thermal energy; kinetic friction and collisions can convert mechanical energy into thermal energy and can be called **dissipative** forces

4 Work

If you are told the magnitude and direction \vec{F} of a force (or you can figure it out using force body diagrams) and also the distance Δd an object travels while this force acts on it, then it will be easy to calculate the work done by the force. The work is

$$W = F_{\parallel}\Delta d, \quad (1)$$

where F_{\parallel} is the component of force parallel to the direction the object moves.

Conservation of mechanical energy

The mechanical energy of a system is conserved when the total work done by external forces that do work on the system, $W_{ext} = 0$, and when none of the internal forces are dissipative forces (i.e. kinetic friction or collisions). Then

$$\Delta E = 0. \quad (2)$$

Remember that when we use gravitational and elastic potential energy, gravity and spring forces do not count as external forces.

Examples of when mechanical energy **is** conserved:

- when the only external forces acting on a system are gravity, elastic forces, or normal forces (which do no work)

Examples of when mechanical energy is **not** conserved:

- when friction slows objects down
- when there are collisions
- when an external force does work on the system

The work-energy theorem

If you can figure out the total work done on an object during a time interval, then you can figure out the change in mechanical energy of the object:

$$\Delta E = W \quad (3)$$

5 Momentum

Massive objects in motion have momentum, which is a vector quantity. Each object of mass m with velocity \vec{v} has a momentum $m\vec{v}$, and the total momentum of the system is the vector sum of the momenta of all its objects.

6 Impulse

If you are told the magnitude of a force (or you can figure it out using a force body diagram) and also the length of time Δt that the force acts on an object, then it will be easy to calculate the impulse done by the force. The impulse is

$$\vec{J} = \vec{F}\Delta t. \quad (4)$$

Conservation of momentum

The total momentum of a system is conserved when there are no external forces acting on the system that do work on it. Momentum is still conserved when there are dissipative forces between objects in the system. Then

$$\Delta\vec{p} = 0. \quad (5)$$

Remember that when we consider momentum, gravity and elastic / spring forces **do** count as external forces, and momentum is not conserved if gravity or springs can do work on objects in the system.

Examples of when momentum **is** conserved:

- collisions in space
- collisions on a frictionless level plane
- when two objects slide on a frictionless plane but scratch and exert friction on each other

Examples of when momentum is **not** conserved:

- when gravity makes objects accelerate
- when friction from the ground slows down objects
- when a person does work on something by pushing it or pulling it

The impulse-momentum theorem

If you can figure out the total impulse done on an object during a time interval, then you can figure out the change in momentum of the object:

$$\Delta\vec{p} = \vec{J} \quad (6)$$

The impulse-momentum equation is equivalent to

$$\vec{F}\Delta t = m\Delta\vec{v}$$

which is really just another way of writing Newton's second law

$$\vec{F} = m\frac{\Delta\vec{v}}{\Delta t} = m\vec{a}.$$

The point of defining impulse is to make the conceptual parallel between the relationship between work/energy and impulse/momentum. If you'd prefer not to think about impulse or the impulse-momentum theorem, just replace this part of the checklist with "Can you figure out the change in the object's speed using $\vec{F} = m\vec{a}$?"