Physics 101

Dr. Roger Nanes

Solutions to Problems - Chapter 1 (Energy)

1. The effect of doing work is to: B) change the amount of energy stored in a system

The amount of energy stored in a system can only be changed by energy transfer into or out of the system. Work is one way to transfer energy (along with heat, waves, etc.) so the effect of doing work on a system is to transfer energy into the system. For example, doing work to lift an object to a height h, changes the amount of energy stored as gravitational potential energy. Pushing on a box along the floor and causing it to speed up does work on the box and, in this case, the work done increases the amount of energy stored in the system (the box) as kinetic energy.

2. For each of the following scenarios, describe as completely as possible the flow of energy, making clear how energy storage, transfer and transformation play a role in the process:

A) *You give a single push to a person on a skateboard who is initially at rest. The skateboard rider rolls along the ground, until he reaches a hill, rolls part way up the hill and then rolls back down the hill.*

When you give a single push to the skateboarder, you exert a force which displaces the skateboarder which means that you do work on the skateboarder. Work is a form of energy transfer and the work done transfers energy into the skateboarder. This energy is stored in the skateboarder as kinetic energy (KE) (he is now in motion). The skateboarder is on the skateboard (slightly above ground) so he has a small amount of gravitational potential energy (GPE) at this time. While the skateboarder rolls along the ground, almost all his stored energy is kinetic energy of motion. The force of friction does work which transfers some energy away from the skateboarder (in the form of heat transfer). When the skateboarder starts to roll up the hill, as his height above the starting level increases, he gains GPE. Also, as he goes up the hill, he slows down and his KE decreases. In this case, we can see that his original KE is being *transformed* to GPE—his total energy remains the same, but it is changing (transforming) from KE to GPE as he slows and gets higher. When his KE has been completely transformed to GPE, the skateboarder is no longer moving and has come to rest on the hill (i.e., he is instantaneously at rest and is now beginning to roll back down.) Once the skateboarder starts to roll back down the ramp, he picks up speed (more kinetic energy) and comes closer to ground (less gravitational potential energy) His GPE is now being transformed back into kinetic energy.

B) *A book, just balanced on the edge of a table, falls off the table onto an egg on the floor below.*

Once the book begins to fall, it moves closer to the ground and its gravitational potential energy decreases. At the same time, the book accelerates and falls faster so its kinetic energy is increases. Since no energy is being transferred into the falling book (by work, heat or sound) as it falls, the total energy of the book will not change (energy can change only when there is energy transferred into or out of the system). Since the total energy does not change, the increase in kinetic energy as the book falls must be balanced by the decrease in gravitational potential energy that occurs. Thus, we say that the gravitational potential energy is *transformed* into kinetic energy.

While the book is falling, the egg is at rest (zero kinetic energy) on the ground (zero gravitational potential energy). (Both the book and the egg also have internal energy simply because they have a temperature and both also have chemical potential energy stored in the arrangement of atoms in the molecules. Since neither of these are affected by the book falling on the egg, they are not discussed any further in this particular problem. When the book hits the egg, the book exerts a force and does work on the egg. Work transfers energy into the egg. Once energy has been transferred into the egg (by the work done by the book), the egg now has energy that it did not have before. Some of this energy in the egg appears as kinetic energy of the shattered and cracked pieces of eggshell. Some of the energy appears as kinetic energy of the fluid inside the egg (and the yolk) in the form of motion as the egg contents splatters out of the now broken shell. Some of the energy that had been transferred into the egg is transferred out of the egg and travels to the ears of the observer in the form of sound.

C) *A cup containing water is placed over a candle and is heated.*

When the candle burns, chemical potential energy stored in the wax is released and is transferred to the cup by heat transfer. Some of the energy in the burning candle is transferred away in the form of visible light (electromagnetic radiation). (You know this must be true because you receive this energy in your eyes and it enables you to see the candle.) Also, some energy from the combustion zone is lost by heating the surrounding air. This energy goes into storage as internal energy of the air which raises its temperature. The energy from the combustion zone of the candle is transferred to the cup by convection (the mechanism for heat transfer in gases). The energy travels through the cup by conduction (the mechanism for heat transfer in solids, involving neighbor-to-neighbor collisions between atoms) and is then transferred to the water in the cup (also by conduction). The water takes the energy that it receives and stores it internally as internal energy, which results in a rise in the temperature of the water in the cup.

3. A wave on a rope has a wavelength of 0.25 m is observed to be moving at a speed of 3 m/s. What is the frequency of the wave?
The velocity of a wave is equal to the product of its frequency times its wavelength: $f\lambda = v$. In this case, $\lambda = 0.25$ and $v = 3$ m/s, so $f = v/\lambda = 3/0.25 = 12$ Hz.

4. What is the wavelength of a radio wave received at 100 megahertz on your dial?
A radio wave is an electromagnetic (E&M) wave, and all E&M waves have the same velocity $c = 3 \times 10^8$ m/s. (You should know this even though the problem does not specifically state it.) A frequency of 100 megahertz is 100×10^6 Hz = 10^8 Hz. The wavelength is then $\lambda = v/f = (3 \times 10^8)/10^8 = 3$ m.

5. What is the period of a visible light wave having a wavelength of 500 nm?
The period (T) of a wave is the reciprocal of its frequency, i.e., $T = 1/f$. We are not given the frequency here, but we are given the wavelength and we know the frequency is $f = v/\lambda$. Since visible light is an E&M wave, $v = 3 \times 10^8$ m/s and, for a λ of 500 nm (which is 500×10^{-9} m = 5×10^{-7} m), we have $f = (3 \times 10^8)/(5 \times 10^{-7}) = 0.6 \times 10^{15} = 6 \times 10^{14}$ Hz. Now, we can find the period as $T = 1/f = 1/(6 \times 10^{14}) = 0.167 \times 10^{-14}$ sec = 1.67×10^{-15} sec.

6. The captain of a boat notices wave crests passing his anchor chain every 5 s. He estimates the distance between wave crests to be 20 m. What is the speed of the waves?
If wave crests pass his anchor every 5 s, that means that one wave passes by the boat every 5 s—this is the period of the wave. The frequency of the wave is the reciprocal of the period, i.e., $f = 1/T = 1/5\ s^{-1}$ (where the s^{-1} designation means "per second" or oscillations per second). Think of it this way: If one wave passes the boat every 5 seconds, then in <u>one</u> second only 1/5 of a wave passes. The distance between wavecrests is the wavelength (λ) and is given in the problem as $\lambda = 20$ m. The speed (or velocity) of a wave is the product of the frequency times the wavelength, i.e., $v = f\lambda = (1/5\ s^{-1})(20\ m) = 4\ m\cdot s^{-1} = 4$ m/s.

7. Two novice homebuilders are arguing over the packing of the glass wool insulation into the walls of the home that they are building. One of the workers argues that it would be better to pack the insulation in tightly to fill all the space between the wallboards. The second worker argues that it would be better to pack the insulation loosely. With which worker do you agree? Explain your thinking.
The insulation material is most effective when it contains the maximum amount of air trapped between its fibers, because air is a very poor thermal conductor. If the insulation is packed very tightly, the trapped air would be "squeezed out" and the insulation properties would be reduced. Thus, it would be better to pack the insulation loosely.

8. Explain why defrosting frozen food occurs more quickly if the food is placed on a slab of black aluminum rather than on a wooden countertop.
Once frozen food is taken out of the freezer, it is much colder than the temperature in the surrounding room. The reason it defrosts at all is because energy is transferred into the frozen item by heat transfer from the warmer environment. (Remember that, without a refrigerator or something to "pump" energy from cold to hot, heat transfer will always occur spontaneously from hot to cold, i.e., from the environment into the frozen food in this example.) As energy leaves the wood or aluminum with which the frozen food is in contact, because aluminum is a better conductor than wood, energy can flow from the interior of the aluminum slab for "delivery" to the frozen food much more efficiently than it can from the interior of a wood slab. Consequently the transfer of energy to the frozen food occurs more rapidly for the aluminum slab. In addition to the greater conductivity of aluminum, if the slab of aluminum is painted black (as stated in the problem) it will absorb energy from the surroundings by electromagnetic radiation (just like black clothing keeps you warmer than white clothing) and "replenishes" the energy that is leaving the slab into the frozen food. The greater conductivity of the aluminum and the greater ability of the black surface to absorb energy both contribute to the faster defrosting of the frozen food.

9. Do you think that a thermos bottle achieves its excellent insulating properties by inhibiting conduction, convection, and/or radiation? Explain your thinking.
A thermos bottle has excellent insulating properties because it inhibits <u>all three</u> forms of heat transfer. The thermos bottle is double-walled glass, with vacuum between the walls. The two inner glass surfaces facing each other are silvered. Recall that conduction is heat transfer that occurs as a result of collisions between neighboring atoms or molecules in a solid material. By definition, a vacuum means that there is no material medium, i.e., there are <u>no</u> atoms or molecules that can transfer the energy by colliding with one another. Similarly, convection is energy transfer carried by mass transport in gases and/or liquids—the wholesale motion of the material (say, air or water) carries the energy from one place to another. If there are no atoms or molecules to carry the energy by their motion through space, there can be no convection. Finally, the silvered walls of the thermos bottle reflects the electromagnetic waves that would normally carry energy out of the hot liquid back into the bottle so that it cannot escape into the outside environment.

10. You hold a strip of aluminum so that one end is in an open flame until it becomes red hot. Describe which mechanisms of heat transfer would be involved in this process.

Energy from the hot combustion zone in the flame is transferred into the aluminum strip by conduction. Once the aluminum strip gets hot, it radiates away energy in the form of electromagnetic radiation. The fact that it is "red hot" is evidence that red visible light waves are being radiated (along with lots of infrared which, however, you cannot see). Energy would also transfer along the length of the aluminum strip to the other end by conduction. Convection does not play a role in the heating of the aluminum strip but the hot air rising from the flame is carried upward by motion of the energetic air molecules by convection.

11. Water conducts heat about 20 times better than does air. If 70˚ air feels warm and comfortable to us, why does 70˚ water feel cool when we swim in it?

Because water is a better conductor than air (about 20 times better, according to the problem), the heat from your body is conducted into the water better than when you are immersed in a "sea" of air. Because the water conducts your body heat away better than air does, the body feels cooler. This is a very similar situation to the demonstration done in class involving the alternating wood and aluminum rings wrapped in paper. Because aluminum is a better conductor than wood, the aluminum conducts the energy away from the hot paper more effectively than the wood does. As a consequence, the paper remains cooler over the aluminum rings and does not char or burn as rapidly as it does in the wood sections.

12. If you were caught in freezing weather with only your own body for a heat source, would you be warmer in an igloo or in a wooden shack?

As discussed in class, the ice crystals that make up the igloo consists of alot of trapped air which is an excellent insulator. This trapped air inhibits conduction of energy from your body ("body heat") through the walls of the igloo much more efficiently than in the case in a wood shack. It is really the air in the igloo ice which is absent in wood, which makes the igloo a better insulator.