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First law of thermodynamics for steady state flow processes worksheets answers

In part 1, we must first find the net heat transfer and net work done from the given information. Metabolism is an interesting example of the first law of thermodynamics in action. Note that $\Delta U = Q - W$. Describe how conservation of energy relates to the first law of thermodynamics. In other words, ΔU is independent of path. Again, consider the internal energy the body has lost. Work, a quite organized process, involves a macroscopic force exerted through a distance. To get a better idea of how to think about the internal energy of a system, let us examine a system going from State 1 to State 2. Thus the change in internal energy is given by the first law of thermodynamics: $\Delta U = Q - W = 15.00 \text{ J} - 6.00 \text{ J} = 9.00 \text{ J}$. Whatever you lose to heat transfer and doing work is replaced by food, so that, in the long run, $\Delta U=0$. Identify the type of energy transferred to your body in each of the following as either internal energy, heat transfer, or doing work: (a) basking in sunlight; (b) eating food; (c) riding an elevator to a higher floor. How much heat transfer occurs from a system, if its internal energy decreased by 150 J while it was doing 30.0 J of work? This process is how dieting produces weight loss. An irreversible process can go in one direction but not the reverse, under a given set of conditions. This process is the intake of one form of energy—light—by plants and its conversion to chemical potential energy. (a) What is the average metabolic rate in watts of a man who metabolizes 10,500 kJ of food energy in one day? (a) How long will the energy in a 1470-kJ (350-kcal) cup of yogurt last in a woman doing work at the rate of 150 W with an efficiency of 20.0% (such as in leisurely climbing stairs)? So the change in internal energy $\Delta U = U2 - U1$ is independent of what caused the change. Give an example of each type of energy, and state specifically how it is either in transit or resides in a system. The first is the atomic and molecular view, which examines the system on the atomic and molecular scale. In part (b), the net heat transfer and work done are given, so the equation can be used directly. How is heat being transferred? Another example of an irreversible thermodynamic process is photosynthesis. The change in the internal energy of the system, ΔU, is related to heat and work by the first law of thermodynamics, $\Delta U = Q - W$. A system does 1.80×108 J of work while 7.50×108 J of heat transfer occurs to the environment. Figure 3. The body adjusts its basal metabolic rate to partially compensate for over-eating or under-eating. The change in internal energy is $\Delta U=Q-W=9.00$ J. What is the work done and what is doing it? Conceptual Questions Describe the photo of the tea kettle at the beginning of this section in terms of heat transfer, work done, and internal energy. The internal energy U of a system depends only on the state of the system and not how it reached that state. This boiling tea kettle represents energy in motion. (c) Compare his work output with the daily output of a 187-W (0.250-horsepower) motor. (See Figure 2.) We will now examine Q, W, and ΔU further. Your basal metabolic rate (BMR) is the rate at which food is converted into heat transfer and work done while the body is at complete rest. (credit: Gina Hamilton) If we are interested in how heat transfer is converted into doing work, then the conservation of energy principle is important. First, consider 40.00 J of heat transfer in and 10.00 J of work out, or $\Delta U1 = Q1 - W1 = 40.00 \text{ J} - 10.00 \text{ J} = 30.00 \text{ J}$. Heat transfer into a system, such as when the Sun warms the air in a bicycle tire, can increase its temperature, and so can work done on the system, as when the bicyclist pumps air into the tire. We can also find the change in internal energy for each of the two steps. Solution for Part 2 Here the net heat transfer and total work are given directly to be $Q=-150.00$ J and $W=-159.00$ J, so that $\Delta U = Q - W = -150.00 \text{ J} - (-159.00 \text{ J}) = 9.00 \text{ J}$. For example, although body fat can be converted to do work and produce heat transfer, work done on the body and heat transfer into it cannot be converted to body fat. The internal energy U of a system is the sum of the kinetic and potential energies of its atoms and molecules. The body stores fat or metabolizes it only if energy intake changes for a period of several days. In particular, which can be stored as such in a system and which cannot? The body will decrease the metabolic rate rather than eliminate its own fat to replace lost food intake. The first law of thermodynamics states that the change in internal energy of a system equals the net heat transfer into the system minus the net work done by the system. One great advantage of conservation laws such as the first law of thermodynamics is that they accurately describe the beginning and ending points of complex processes, such as metabolism and photosynthesis, without regard to the complications in between. Figure 1. What are some of the major characteristics of heat transfer, doing work, and energy in the body? It has also been determined experimentally that the internal energy U of a system depends only on the state of the system and not how it reached that state. Highly dependent on path. Can be divided into many subcategories, such as thermal and chemical energy. The first law of thermodynamics applies the conservation of energy principle to systems where heat transfer and doing work are the methods of transferring energy into and out of the system. (Food intake may be considered as work done on the body.) (b) Plants convert part of the radiant heat transfer in sunlight to stored chemical energy, a process called photosynthesis. The energy content of gasoline is 1.3×108 J/gal. Then the first law of thermodynamics ($\Delta U = Q - W$) can be used to find the change in internal energy. Section Summary The first law of thermodynamics is given as $\Delta U = Q - W$, where ΔU is the change in internal energy of a system, Q is the net heat transfer (the sum of all heat transfer into and out of the system), and W is the net work done (the sum of all work done on or by the system). Characterized by random molecular motion. (a) How much food energy will a man metabolize in the process of doing 35.0 kJ of work with an efficiency of 5.00%? Change in internal energy is path independent. Figure 2. Weight loss is also aided by the quite low efficiency of the body in converting internal energy to work, so that the loss of internal energy resulting from doing work is much greater than the work done.It should be noted, however, that living systems are not in thermalequilibrium. Figure 4. Heat transfer Q and work done W are always energy in transit, whereas internal energy U is energy stored in a system. (b) What is the maximum amount of work in joules he can do without breaking down fat, assuming a maximum efficiency of 20.0%? The first law gives the relationship between heat transfer, work done, and the change in internal energy of a system. The processes are quite different. Since the body is inefficient, the excess heat produced must be dissipated through sweating, breathing, etc. In equation form, the first law of thermodynamics is $\Delta U = Q - W$. Considering the body as the system of interest, we can use the first law to examine heat transfer, doing work, and internal energy in activities ranging from sleep to heavy exercise. Note also that if more heat transfer into the system occurs than work done, the difference is stored as internal energy. Identify instances of the first law of thermodynamics working in everyday situations, including biological metabolism. Many detailed experiments have verified that $\Delta U = Q - W$, where ΔU is the change in total kinetic and potential energy of all atoms and molecules in a system. Recall that kinetic plus potential energy is called mechanical energy. The system has internal energy U1 in State 1, and it has internal energy U2 in State 2, no matter how it got to either state. The reverse is true if you eat too little. If you overeat repeatedly, then ΔU is always positive, and your body stores this extra internal energy as fat. Similarly, the total work is the work done by the system minus the work done on the system, or $W = 10.00 \text{ J} - 4.00 \text{ J} = 6.00 \text{ J}$. How does the kettle maintain its internal energy? We use the following sign conventions: if Q is positive, then there is a net heat transfer into the system; if W is positive, then there is net work done by the system. (b) Does the time found in part (a) imply that it is easy to consume more food energy than you can reasonably expect to work off with exercise? Macroscopically, we define the change in internal energy ΔU to be that given by the first law of thermodynamics: $\Delta U = Q- W$. If ΔU is negative for a few days, then the body metabolizes its own fat to maintain body temperature and do work that takes energy from the body. Table 1. Exercise helps to lose weight, because it produces both heat transfer from your body and work, and raises your metabolic rate even when you are at rest. Both applications of the first law of thermodynamics are illustrated in Figure 4. This means Q is negative. This means W is positive. This energy is measured by burning food in a calorimeter, which is how the units are determined. If you eat just the right amount of food, then your average internal energy remains constant. Life is not always this simple, as any dieter knows. How do heat transfer and internal energy differ? Heat transferred out of the body (Q) and work done by the body (W) remove internal energy, while food intake replaces it. Later, there is heat transfer of 25.00 J out of the system while 4.00 J of work is done on the system. If you run down some stairs and stop, what happens to your kinetic energy and your initial gravitational potential energy? We now take another look at these topics via the first law of thermodynamics. Once you have been on a major diet, the next one is less successful because your body alters the way it responds to low energy intake. Q represents the net heat transfer—it is the sum of all heat transfers into and out of the system. This independence means that if we know the state of a system, we can calculate changes in its internal energy U from a few macroscopic variables. (b) Heat transfer removes 150.00 J from the system while work puts 159.00 J into it, producing an increase of 9.00 J in internal energy. Q is positive for net heat transfer into the system. Note that the change in the system in both parts is related to ΔU and not to the individual Qs or Ws involved. You will chill more easily and feel less energetic as a result of the lower metabolic rate, and you will not lose weight as fast as before. Internal energy is a form of energy completely different from either heat or work. In thermodynamics, we often use the macroscopic picture when making calculations of how a system behaves, while the atomic and molecular picture gives underlying explanations in terms of averages and distributions. We shall see this again in later sections of this chapter. There are three places this internal energy can go—to heat transfer, to doing work, and to stored fat (a tiny fraction also goes to cell repair and growth). The first law of thermodynamics is the conservation-of-energy principle stated for a system where heat and work are the methods of transferring energy for a system in thermal equilibrium. What is the change in internal energy of a system which does 4.50×105 J of work while 3.00×106 J of heat transfer occurs into the system, and 8.00×106 J of heat transfer occurs to the environment? Heat transfer and doing work take internal energy out of the body, and food puts it back. Eating increases the internal energy of the body by adding chemical potential energy (this is an unromantic view of a good steak). This uncertainty is an important point. More specifically, U is found to be a function of a few macroscopic quantities (pressure, volume, and temperature, for example), independent of past history such as whether there has been heat transfer or work done. Table 1 presents a summary of terms relevant to the first law of thermodynamics. Problems & Exercises What is the change in internal energy of a car if you put 12.0 gal of gasoline into its tank? Is it consistent with the fact that you quickly warm up when exercising? If the system starts out in the same state in (a) and (b), it will end up in the same final state in either case—its final state is related to internal energy, not how that energy was acquired. What is the change in internal energy of the system assuming no other changes (such as in temperature or by the addition of fuel)? Because it is impossible to keep track of all individual atoms and molecules, we must deal with averages and distributions. (a) A total of 15.00 J of heat transfer occurs into the system, while work takes out a total of 6.00 J. W is the total work done on and by the system. How do they differ in the types of energy considered? (That is, there is no other energy transfer.) (b) What is her efficiency? The body metabolizes all the food we consume. Another fact is that the body usually does work on the outside world. Path dependent. Here ΔU is the change in internal energy U of the system. The first law of thermodynamics is actually the law of conservation of energy stated in a form most useful in thermodynamics. Suppose a woman does 500 J of work and 9500 J of heat transfer occurs into the environment in the process. Q entering a system is positive. Metabolism of living organisms, and photosynthesis of plants, are specialized types of heat transfer, doing work, and internal energy of systems. Nutritionists and weight-watchers tend to use the dietary calorie, which is frequently called a Calorie (spelled with a capital C). Thus $\Delta U = Q - W$. Q is the net heat transferred into the system—that is, Q is the sum of all heat transfer into and out of the system. (a) A woman climbing the Washington Monument metabolizes 6.00×102 kJ of food energy. Human Metabolism and the First Law of Thermodynamics Human metabolism is the conversion of food into heat transfer, work, and stored fat. Suppose there is heat transfer of 40.00 J to a system, while the system does 10.00 J of work. (b) How much heat transfer occurs to the environment to keep his temperature constant? In chemistry and biochemistry, one calorie (spelled with a lowercase c) is defined as the energy (or heat transfer) required to raise the temperature of one gram of pure water by one degree Celsius. Food energy is reported in a special unit, known as the Calorie. By path, we mean the method of getting from the starting point to the ending point. Discussion on Part 2 A very different process in part 2 produces the same 9.00-J change in internal energy as in part 1. Depends only on the state of a system (such as its P, V, and T), not on how the energy entered the system. Basically, metabolism is an oxidation process in which the chemical potential energy of food is released. This path independence means that internal energy U is easier to consider than either heat transfer or work done. An organized, orderly process. For one, body temperature is normally kept constant by heat transfer to the surroundings. This means that one dietary Calorie is equal to one kilocalorie for the chemist, and one must be careful to avoid confusion between the two. Solution for Part 1 The net heat transfer is the heat transfer into the system minus the heat transfer out of the system, or $Q = 40.00 \text{ J} - 25.00 \text{ J} = 15.00 \text{ J}$. The first law of thermodynamics and the conservation of energy, as discussed in Conservation of Energy, are clearly related. (See Figure 3). One food Calorie is the energy needed to raise the temperature of one kilogram of water by one degree Celsius. Otherwise, we could skip lunch by sunning ourselves or by walking down stairs. first law of thermodynamics: states that the change in internal energy of a system equals the net heat transfer into the system minus the net work done by the system internal energy: the sum of the kinetic and potential energies of a system's atoms and molecules human metabolism: conversion of food into heat transfer, work, and stored fat 1. 1.6×109 J 3. -9.30×108 J 5. (a) -1.0×104 J , or -2.39 kcal; (b) 5.00% 7. (a) 122 W; (b) 2.10×106 J; (c) Work done by the motor is 1.61×107 J; thus the motor produces 7.67 times the work done by the man 9. (a) 492 kJ; (b) This amount of heat is consistent with the fact that you warm quickly when exercising. In such situations, then, the body loses internal energy, since $\Delta U = Q - W$ is negative. Once the temperature increase has occurred, it is impossible to tell whether it was caused by heat transfer or by doing work. What is the net change in internal energy of the system? Nevertheless, heat and work can produce identical results.For example, both can cause a temperature increase. The total change is the sum of these two steps, or $\Delta U = \Delta U1 + \Delta U2 = 30.00 \text{ J} + (-21.00 \text{ J}) = 9.00 \text{ J}$. If her efficiency is 18.0%, how much heat transfer occurs to the environment to keep her temperature constant? This implies that food input is in the form of work. Heat transfer, a less organized process, is driven by temperature differences. Why is this independence important? As the entire system gets hotter, work is done—from the evaporation of the water to the whistling of the kettle. W is positive when more work is done by the system than on it. Now consider the effects of eating. Both Q and W are energy in transit; only ΔU represents an independent quantity capable of being stored. Thus internal energy is the sum of atomic and molecular mechanical energy. (b) Discuss the amount of heat transfer found in (a). Two different processes produce the same change in a system. However, both can change the internal energy U of a system. The water in the kettle is turning to water vapor because heat is being transferred from the stove to the kettle. W done by a system (either against an external force or to increase the volume of the system) is positive. Internal Energy U We can think about the internal energy of a system in two different but consistent ways. Heat engines are a good example of this—heat transfer into them takes place so that they can do work. W Work—energy transferred by a force moving through a distance. (a) The first law of thermodynamics applied to metabolism. Parts 1 and 2 present two different paths for the system to follow between the same starting and ending points, and the change in internal energy for each is the same—it is independent of path. Q Heat—energy transferred because of a temperature difference. The body provides us with an excellent indication that many thermodynamic processes are irreversible. A second way to view the internal energy of a system is in terms of its macroscopic characteristics, which are very similar to atomic and molecular average values. Now consider 25.00 J of heat transfer out and 4.00 J of work in, or $\Delta U2 = Q2 - W2 = -25.00 \text{ J} - (-4.00 \text{ J}) = -21.00 \text{ J}$. Calculate changes in the internal energy of a system, after accounting for heat transfer and work done. By the end of this section, you will be able to: Define the first law of thermodynamics. What is the change in internal energy of a system when a total of 150.00 J of heat transfer occurs out of (from) the system and 159.00 J of work is done on the system? Heat transfer and work are both energy in transit—neither is stored as such in a system. All other factors, such as the car's temperature, are constant. Discussion on Part 1 No matter whether you look at the overall process or break it into steps, the change in internal energy is the same. W is the net work done by the system—that is, W is the sum of all work done on or by the system. Heat Q and Work W Heat transfer (Q) and doing work (W) are the two everyday means of bringing energy into or taking energy out of a system. (a) What is the decrease in her internal energy, assuming no change in temperature or consumption of food? For example, in the topic of entropy, calculations will be made using the atomic and molecular view. Both Q and Wdepend on path, but ΔU does not. Give an explanation of how food energy (calories) can be viewed as molecular potential energy (consistent with the atomic and molecular definition of internal energy). Summary of Terms for the First Law of Thermodynamics, $\Delta U = Q - W$ Term Definition U Internal energy—the sum of the kinetic and potential energies of a system's atoms and molecules. The system ends up in the same state in both parts. So positive Q adds energy to the system and positive W takes energy from the system.

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