CHAPTER 20
THE SECOND LAW OF THERMODYNAMICS

Discussion Questions

Q20.1 The cycle approaches reversibility as the temperature difference between the stove and water approaches zero. In this limit an infinitesimal change in the temperature of the stove can cause the liquid to vapor phase transition to reverse direction.

Q20.2 Reversible: (1) Light, frictionless pulley with a string passing over it and two almost equal masses m_1 and m_2 suspended from the two ends of the string. m_1 descends if it is slightly heavier than m_2 and ascends if m_2 is slightly heavier. A small change in one of the masses causes the system to move in the opposite direction. (2) A block on a horizontal frictionless surface and attached to one end of a spring. The block is pushed against the spring and compresses it. Then the applied force is kept almost equal in magnitude to the spring force. If the applied force is increased slightly the block moves one direction and if the applied force is decreased slightly the block moves back the other direction.

Irreversible: (1) A bullet is fired through a block of wood that is initially at rest on a horizontal frictionless surface. The bullet passes through the block and emerges with reduced speed. Mechanical energy is lost in the collision. The bullet can be sent back through the block by reversing its direction but mechanical energy is again lost in the collision and after the collision the block isn't at rest and the bullet doesn't have the same speed as it did before the original collision.ad (2) A block slides down an incline that has friction. The block has speed v when it reaches the bottom of the incline. If the block is at sent up the incline with initial speed v it won't return to its initial height, due to mechanical energy lost to friction work.

Q20.3 For a refrigerator device, $|Q_\text{H}|=|Q_\text{C}|+|W|$. This says that the heat energy $|Q_\text{H}|$ deposited in the room is the same as the heat energy $|Q_\text{C}|$ removed from the food compartment plus the amount of mechanical energy required to operate the refrigerator (inputed to the device as electrical energy). The tubing is where the heat flows from the device into the room.

Q20.4 The refrigerator operates on a cycle and $Q=W$. $Q=Q_\text{C}+Q_\text{H}$. For a refrigerator $Q_\text{C}>0$ and $Q_\text{H}<0$ and $W<0$, so $|Q_\text{C}|-|Q_\text{H}|=-|W|$. $|Q_\text{H}|=|Q_\text{C}|+|W|$. More heat is delivered to the room than is taken in at the food compartment. Doing this will heat the room. The cooler of ice will cool the room until all the ice is gone. This is not a cyclic process. Heat energy leaves the room and goes into the ice as it changes phase.

Q20.5 For an air conditioner or refrigerator the amount of heat $|Q_\text{H}|$ that flows out of the device is greater than the heat $|Q_\text{C}|$ that flows into the device. In fact, $|Q_\text{H}|=|Q_\text{C}|+|W|$, where $|W|$ is the energy supplied to operate the device. If an air conditioner is set on the floor and plugged in, $|Q_\text{C}|$ is removed from the room but $|Q_\text{H}|$ is ejected into the room. Since $|Q_\text{H}|$ is larger than $|Q_\text{C}|$, the room is heated rather than cooled. A refrigerator also adds heat to the room in which it is placed. That heat must be removed, for example by a window air conditioner, or else the room will be heated.

Q20.6 It is not a violation to convert mechanical energy completely into heat. This is what happens, for example, when a block slides along a horizontal surface and is stopped by friction. The work done by friction converts all of the initial kinetic energy of the block into thermal energy. It is a violation to convert heat completely into work. This would be a 100% efficient heat engine and is prohibited by the second law.

Q20.7 The filter would lower the average speed of air molecules in the house and this would correspond to a lowering of the temperature of that air. The filter would violate the Clausius statement of the second law.

Q20.8 The energy output exceeds the energy input and this violates conservation of energy.

Q20.9 Work is done by the wind and this results in a transfer of heat from the cloth into the surrounding air; the system acts as a refrigerator.

Q20.10 In the Carnot cycle the heat flows occur in isothermal processes with an infinitesimal temperature difference between the working substance of the engine and the reservoir. Therefore, the heat flows occur in reversible processes. For the Otto cycle the heat flows occur in constant volume processes where there is a finite temperature difference between the working substance and the reservoirs. The Carnot cycle is reversible; the Otto cycle is not.

Q20.11 Heat flow in an isolated system is always in the direction from high temperature to low temperature. Work must be supplied to move heat in the opposite direction and more work is needed the greater the temperature difference.

Q20.12 If $T_{\mathrm{C}} = T_{\mathrm{H}}$, $e = 0$. The Carnot engine cannot operate unless the two heat reservoirs are at different temperatures. If $T_{\mathrm{C}} = 0\ \mathrm{K}$, $e = 1$. If the low temperature reservoir were at absolute zero, no waste heat Q_{C} would be deposited there and the Carnot cycle would be 100% efficient.

Q20.13 No. A Carnot cycle is 100% efficient only if $T_{\mathrm{C}} = 0\ \mathrm{K}$, and this is impossible to achieve. Any other cycle would be less efficient.

Q20.14 The room is the high temperature reservoir for the device. The efficiency is lower the greater the temperature of the room. The refrigerator consumes more power when the room temperature is $20^{\circ}\mathrm{C}$.

Q20.15 No. 576 J of heat energy is placed into the high temperature reservoir. The net heat flow for the device is $+346\ \mathrm{J} - 576\ \mathrm{J} = -230\ \mathrm{J}$, which means a net flow of 230 J of energy out of the device. But the work done on the refrigerator's working substance puts 230 J of energy into the device and energy is conserved for the device. The heat added to the high temperature reservoir is the sum of the amount of heat taken out of the low temperature reservoir plus the energy added to the system by *W*.

Q20.16 The change in entropy depends not only on the heat flow but is also inversely proportional to the Kelvin temperature at which that heat flow occurs. The negative heat flow out of the hot object occurs at a higher temperature than the positive heat flow into the cold object, so the positive entropy change is greater than the negative entropy change and the net entropy change is positive.

Q20.17 The mixed water is less organized. In the free expansion the atoms become less confined in space. An increase in thermal energy means more kinetic energy in the random motion of the atoms of the objects. In all these processes the entropy of the system increases.

Q20.18 Eq.(20.19) only applies to a reversible process and the free expansion is not reversible. In a reversible process between the same initial and final states of the gas (an isothermal expansion) there is a heat flow into the gas. And for this process Eq.(20.19) gives the entropy change. Entropy is a state function and the entropy change is path independent. So, the entropy change for the isothermal expansion equals the entropy change for the free expansion and is not zero.

Q20.19 The earth and sun are not in thermal equilibrium; the earth has a much lower temperature than the sun. When heat is transferred from the sun to the earth the energy transfer from the sun occurs at a higher temperature than the energy transfer to the earth. So, the entropy decrease of the sun has a smaller magnitude than the entropy increase of the earth. The total entropy change of the isolated system of the earth plus sun is positive, in agreement with the second law of thermodynamics. Radiation does not differ from other modes of heat transfer with respect to entropy changes.

Q20.20 The first law of thermodynamics is a statement of conservation of energy. If the magnitude of heat that flows out of the cold object equals the amount that flows into the hot object, the first law is satisfied. But this process would violate the second law. For an isolated system (the hot and cold objects) the total entropy would decrease (see Q20.16) in the process and this violates the second law.

Q20.21 You would not see any process that violates conservation of energy or conservation of momentum. These laws still apply when time is reversed. Any irreversible process in which entropy of an isolated system increases will violate the second law of thermodynamics when run in reverse. A simple example is a box sliding along the floor and being stopped by friction. In the real life direction of time kinetic energy is converted entirely into thermal energy. When time is reversed the box moves with increasing speed as thermal energy is converted to kinetic energy. This violates the second law of thermodynamics.

Q20.22 Life forms are not an isolated system. Processes are allowed in which objects have a decrease in entropy, so long as the objects interact with other objects whose entropy increases.

Q20.23 It is not a violation of the second law of thermodynamics because the plant is not an isolated system. The plant receives energy from its environment, from the radiative energy of sunlight.