***University Physics Volume II***

**Unit 1: Thermodynamics**

**Chapter 4: The Second Law of Thermodynamics**

**Conceptual Questions**

1. State an example of a process that occurs in nature that is as close to reversible as it can be.

Solution

Some possible solutions are frictionless movement; restrained compression or expansion; energy transfer as heat due to infinitesimal temperature nonuniformity; electric current flow through a zero resistance; restrained chemical reaction; and mixing of two samples of the same substance at the same state.

1. Explain in practical terms why efficiency is defined as 

Solution

Efficiency is practically defined as “what you get” divided by “what you pay for.” You are getting work and paying for it by heat from the hot reservoir.

1. If the refrigerator door is left open, what happens to the temperature of the kitchen?

Solution

The temperature increases since the heat output behind the refrigerator is greater than the cooling from the inside of the refrigerator.

1. Is it possible for the efficiency of a reversible engine to be greater than 1.0? Is it possible for the coefficient of performance of a reversible refrigerator to be less than 1.0?

Solution

Without additional work added, the efficiency of a reversible engine must be less than 1.0 and the coefficient of performance of a refrigerator can never be less than 1.0.

1. In the text, we showed that if the Clausius statement is false, the Kelvin statement must also be false. Now show the reverse, such that if the Kelvin statement is false, it follows that the Clausius statement is false.

Solution

If we combine a perfect engine and a real refrigerator with the engine converting heat *Q* from the hot reservoir into work  to drive the refrigerator, then the heat dumped to the hot reservoir by the refrigerator will be **, resulting in a perfect refrigerator transferring heat ** from the cold reservoir to hot reservoir without any other effect.

1. Why don’t we operate ocean liners by extracting heat from the ocean or operate airplanes by extracting heat from the atmosphere?

Solution

It takes too much energy or work to extract heat from the large temperature differences.

1. Discuss the practical advantages and disadvantages of heat pumps and electric heating.

Solution

Heat pumps can efficiently extract heat from the ground to heat on cooler days or pull heat out of the house on warmer days. The disadvantage of heat pumps are that they are more costly than alternatives, require maintenance, and will not work efficiently when temperature differences between the inside and outside are very large. Electric heating is much cheaper to purchase than a heat pump; however, it may be more costly to run depending on the electric rates and amount of usage.

1. The energy output of a heat pump is greater than the energy used to operate the pump. Why doesn’t this statement violate the first law of thermodynamics?

Solution

There is no additional heat added, only heat moving from the cold reservoir to the hot reservoir. This is against its spontaneous flow, so work has to be done.

1. Speculate as to why nuclear power plants are less efficient than fossil-fuel plants based on temperature arguments.

Solution

A nuclear reactor needs to have a lower temperature to operate, so its efficiency will not be as great as a fossil-fuel plant. This argument does not take into consideration the amount of energy per reaction: Nuclear power has a far greater energy output than fossil fuels.

1. An ideal gas goes from state  to state  when it is allowed to expand freely. Is it possible to represent the actual process on a *pV* diagram? Explain.

Solution

All you can do is plot the endpoints. The path is not well defined; however, the temperature is the same at both points.

1. To increase the efficiency of a Carnot engine, should the temperature of the hot reservoir be raised or lowered? What about the cold reservoir?

Solution

In order to increase the efficiency, the temperature of the hot reservoir should be raised, and the cold reservoir should be lowered as much as possible. This can be seen in .

1. How could you design a Carnot engine with  efficiency?

Solution

You can get close to  efficiency if the cold reservoir is near a temperature of 0 K; however, to have an exactly  efficient Carnot engine, one would need the cold reservoir to be at 0 K.

1. What type of processes occur in a Carnot cycle?

Solution

adiabatic and isothermal processes

1. Does the entropy increase for a Carnot engine for each cycle?

Solution

Ideally, a Carnot engine has no entropy increase; however, to make a Carnot engine that operates in this ideal cycle is nearly impossible, so some slight amount of entropy will increase.

1. Is it possible for a system to have an entropy change if it neither absorbs nor emits heat during a reversible transition? What happens if the process is irreversible?

Solution

Entropy will not change if it is a reversible transition but will change if the process is irreversible.

1. Are the entropy changes of the *systems* in the following processes positive or negative? (a) *water vapor* that condenses on a cold surface; (b) gas in a container that leaks into the surrounding atmosphere; (c) an *ice cube* that melts in a glass of lukewarm water; (d) the *lukewarm water* of part (c); (e) a *real heat engine* performing a cycle; (f) *food* cooled in a refrigerator.

Solution

a. negative; b. positive; c. positive; d. negative; e. positive; f. negative

1. Discuss the entropy changes in the systems of Question 21.10 in terms of disorder.

Solution

Entropy is a function of disorder, so all the answers apply here as well.

**Problems**

1. A tank contains 111.0 g chlorine gas (Cl2), which is at temperature 82.0 °C and absolute pressure  The temperature of the air outside the tank is 20.0 °C. The molar mass of  is 70.9 g/mol. (a) What is the volume of the tank? (b) What is the internal energy of the gas? (c) What is the work done by the gas if the temperature and pressure inside the tank drop to 31.0 °C and 3.80 × 105 Pa, respectively, due to a leak?

Solution

a. ; b. ; c. 0 J

1. A mole of ideal monatomic gas at  and 1.00 atm is warmed up to expand isobarically to triple its volume. How much heat is transferred during the process?

Solution



1. A mole of an ideal gas at pressure 4.00 atm and temperature 298 K expands isothermally to double its volume. What is the work done by the gas?

Solution



1. After a free expansion to quadruple its volume, a mole of ideal diatomic gas is compressed back to its original volume adiabatically and then cooled down to its original temperature. What is the minimum heat removed from the gas in the final step to restoring its state?

Solution



1. An engine is found to have an efficiency of 0.40. If it does 200 J of work per cycle, what are the corresponding quantities of heat absorbed and discharged?

Solution

500 J, 300 J

1. In performing 100.0 J of work, an engine discharges 50.0 J of heat. What is the efficiency of the engine?

Solution

0.667

1. An engine with an efficiency of 0.30 absorbs 500 J of heat per cycle. (a) How much work does it perform per cycle? (b) How much heat does it discharge per cycle?

Solution

a. 150 J; b. 350 J

1. It is found that an engine discharges 100.0 J while absorbing 125.0 J each cycle of operation. (a) What is the efficiency of the engine? (b) How much work does it perform per cycle?

Solution

a. 0.200; b. 25.0 J

1. The temperature of the cold reservoir of the engine is 300 K. It has an efficiency of 0.30 and absorbs 500 J of heat per cycle. (a) How much work does it perform per cycle? (b) How much heat does it discharge per cycle?

Solution

a. 150 J; b. 350 J

1. An engine absorbs three times as much heat as it discharges. The work done by the engine per cycle is 50 J. Calculate (a) the efficiency of the engine, (b) the heat absorbed per cycle, and (c) the heat discharged per cycle.

Solution

a. 0.67; b. 75 J; c. 25 J

1. A coal power plant consumes 100,000 kg of coal per hour and produces 500 MW of power. If the heat of combustion of coal is 30 MJ/kg, what is the efficiency of the power plant?

Solution

60%

1. A refrigerator has a coefficient of performance of 3.0. (a) If it requires 200 J of work per cycle, how much heat per cycle does it remove the cold reservoir? (b) How much heat per cycle is discarded to the hot reservoir?

Solution

a. 600 J; b. 800 J

1. During one cycle, a refrigerator removes 500 J from a cold reservoir and discharges 800 J to its hot reservoir. (a) What is its coefficient of performance? (b) How much work per cycle does it require to operate?

Solution

a. 2.67; b. 300 J

1. If a refrigerator discards 80 J of heat per cycle and its coefficient of performance is 6.0, what are (a) the quantity off heat it removes per cycle from a cold reservoir and (b) the amount of work per cycle required for its operation?

Solution

a. 69 J; b. 11 J

1. A refrigerator has a coefficient of performance of 3.0. (a) If it requires 200 J of work per cycle, how much heat per cycle does it remove the cold reservoir? (b) How much heat per cycle is discarded to the hot reservoir?

Solution

a. 600J; b. 800 J

1. The temperature of the cold and hot reservoirs between which a Carnot refrigerator operates are  and , respectively. Which is its coefficient of performance?

Solution

1.58

1. Suppose a Carnot refrigerator operates between  Calculate the amount of work required to extract 1.0 J of heat from the cold reservoir if (a) , ; (b) , ; (c) , ; and (d) , .

Solution

a. 0.07 J; b. 0.50 J; c. 2.0 J; d. 

1. A Carnot engine operates between reservoirs at 600 and 300 K. If the engine absorbs 100 J per cycle at the hot reservoir, what is its work output per cycle?

Solution

50 J

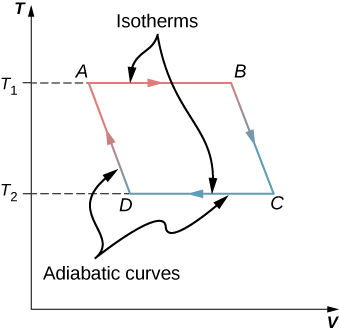
1. A 500-W motor operates a Carnot refrigerator between  and . (a) What is the amount of heat per second extracted from the inside of the refrigerator? (b) How much heat is exhausted to the outside air per second?

Solution

a. 3830 J/s; b. 4330 J/s

1. Sketch a Carnot cycle on a temperature-volume diagram.

Solution



1. A Carnot heat pump operates between  and . How much heat is exhausted into the interior of a house for every 1.0 J of work done by the pump?

Solution

14 J

1. An engine operating between heat reservoirs at  and  extracts 1000 J per cycle from the hot reservoir. (a) What is the maximum possible work that engine can do per cycle? (b) For this maximum work, how much heat is exhausted to the cold reservoir per cycle?

Solution

a. 381 J; b. 619 J

1. Suppose a Carnot engine can be operated between two reservoirs as either a heat engine or a refrigerator. How is the coefficient of performance of the refrigerator related to the efficiency of the heat engine?

Solution



1. A Carnot engine is used to measure the temperature of a heat reservoir. The engine operates between the heat reservoir and a reservoir consisting of water at its triple point. (a) If 400 J per cycle are removed from the heat reservoir while 200 J per cycle are deposited in the triple-point reservoir, what is the temperature of the heat reservoir? (b) If 400 J per cycle are removed from the triple-point reservoir while 200 J per cycle are deposited in the heat reservoir, what is the temperature of the heat reservoir?

Solution

a. 546 K; b. 137 K

1. What is the minimum work required of a refrigerator if it is to extract 50 J per cycle from the inside of a freezer at  and exhaust heat to the air at 25 °C?

Solution

6.65 J

1. Two hundred joules of heat are removed from a heat reservoir at a temperature of 200 K. What is the entropy change of the reservoir?

Solution

–1 J/K

1. In an isothermal reversible expansion at 27 °C, an ideal gas does 20 J of work. What is the entropy change of the gas?

Solution

0.067 J/K

1. An ideal gas at 300 K is compressed isothermally to one-fifth its original volume. Determine the entropy change per mole of the gas.

Solution

–13 J(K mole)

1. What is the entropy change of 10 g of steam at  when it condenses to water at the same temperature?

Solution

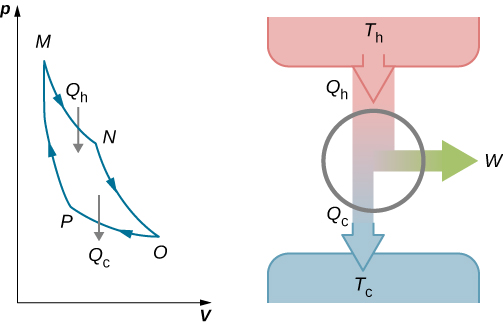
–61 J/K

1. A metal rod is used to conduct heat between two reservoirs at temperatures respectively. When an amount of heat *Q* flows through the rod from the hot to the cold reservoir, what is the net entropy change of the rod, the hot reservoir, the cold reservoir, and the universe?

Solution



1. For the Carnot cycle of the figure below, what is the entropy change of the hot reservoir, the cold reservoir, and the universe?



Solution



1. A 5.0-kg piece of lead at a temperature of  is placed in a lake whose temperature is. Determine the entropy change of (a) the lead piece, (b) the lake, and (c) the universe.

Solution

a. –709 J/K; b. 1300 J/K; c. 591 J/K

1. One mole of an ideal gas doubles its volume in a reversible isothermal expansion. (a) What is the change in entropy of the gas? (b) If 1500 J of heat are added in this process, what is the temperature of the gas?

Solution

a. 5.76 J/K; b. 260 K

1. An ideal monatomic gas is confined to a rigid container. When heat is added reversibly to the gas, its temperature changes from  (a) How much heat is added? (b) What is the change in entropy of the gas?

Solution

a. ; b. 

1. (a) A 5.0-kg rock at a temperature of  is dropped into a shallow lake also at  from a height of . What is the resulting change in entropy of the universe? (b) If the temperature of the rock is  when it is dropped, what is the change of entropy of the universe? Assume that air friction is negligible (not a good assumption) and that  is the specific heat of the rock.

Solution

a. 170 J/K; b. 290 J/K

1. A copper rod of cross-sectional area  and length 5.0 m conducts heat from a heat reservoir at 373 K to one at 273 K. What is the time rate of change of the universe’s entropy for this process?

Solution



1. Fifty grams of water at  is heated until it becomes vapor at . Calculate the change in entropy of the water in this process.

Solution

360 J/K

1. Fifty grams of water at  are changed into vapor at . What is the change in entropy of the water in this process?

Solution

430 J/K

1. In an isochoric process, heat is added to 10 mol of monoatomic ideal gas whose temperature increases from 273 to 373 K. What is the entropy change of the gas?

Solution

39 J/K

1. Two hundred grams of water at  is brought into contact with a heat reservoir at . After thermal equilibrium is reached, what is the temperature of the water? Of the reservoir? How much heat has been transferred in the process? What is the entropy change of the water? Of the reservoir? What is the entropy change of the universe?

Solution

, , , 215 J/K, –190 J/K, 25 J/K

1. Suppose that the temperature of the water in the previous problem is raised by first bringing it to thermal equilibrium with a reservoir at a temperature of  and then with a reservoir at . Calculate the entropy changes of (a) each reservoir, (b) of the water, and (c) of the universe.

Solution

a. –110 J/K and –95 J/K; b. 220 J/K; c. 15 J/K

1. Two hundred grams of water at  is brought into contact into thermal equilibrium successively with reservoirs at , , , and . (a) What is the entropy change of the water? (b) Of the reservoir? (c) What is the entropy change of the universe?

Solution

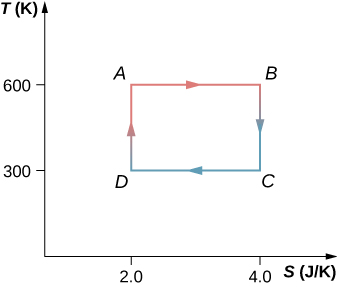
, , 

1. (a) Ten grams of  starts as ice at 0 °C. The ice absorbs heat from the air (just above 0 °C) until all of it melts. Calculate the entropy change of the H2O, of the air, and of the universe. (b) Suppose that the air in part (a) is at 20 °C rather than 0 °C and that the ice absorbs heat until it becomes water at 20 °C. Calculate the entropy change of the H2O, of the air, and of the universe. (c) Is either of these processes reversible?

Solution

a. 12 J/K, –12 J/K, zero; b. 15 J/K, –14 J/K, 1 J/K; c. part (a) is reversible, while part (b) is irreversible

1. The Carnot cycle is represented by the temperature-entropy diagram shown below. (a) How much heat is absorbed per cycle at the high-temperature reservoir? (b) How much heat is exhausted per cycle at the low-temperature reservoir? (c) How much work is done per cycle by the engine? (d) What is the efficiency of the engine?



Solution

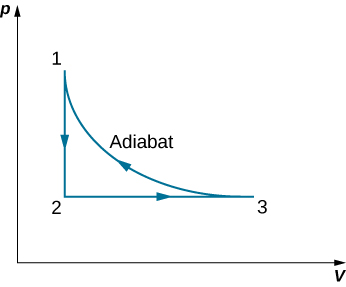
a. 1200 J; b. 600 J; c. 600 J; d. 0.50

1. A Carnot engine operating between heat reservoirs at 500 and 300 K absorbs 1500 J per cycle at the high-temperature reservoir. (a) Represent the engine’s cycle on a temperature-entropy diagram. (b) How much work per cycle is done by the engine?

Solution

600 J

1. A monoatomic ideal gas (*n* moles) goes through a cyclic process shown below. Find the change in entropy of the gas in each step and the total entropy change over the entire cycle.



Solution



1. A Carnot engine has an efficiency of 0.60. When the temperature of its cold reservoir changes, the efficiency drops to 0.55. If initially , determine (a) the constant value of  and (b) the final value of .

Solution

a. ; b. 

1. A Carnot engine performs 100 J of work while discharging 200 J of heat each cycle. After the temperature of the hot reservoir only is adjusted, it is found that the engine now does 130 J of work while discarding the same quantity of heat. (a) What are the initial and final efficiencies of the engine? (b) What is the fractional change in the temperature of the hot reservoir?

Solution

a. 0.33, 0.39; b. 0.91

1. A Carnot refrigerator exhausts heat to the air, which is at a temperature of 25 °C. How much power is used by the refrigerator if it freezes 1.5 g of water per second? Assume the water is at 0 °C.

Solution

0.16 W

**Additional Problems**

1. A 300-W heat pump operates between the ground, whose temperature is , and the interior of a house at . What is the maximum amount of heat per hour that the heat pump can supply to the house?

Solution



1. An engineer must design a refrigerator that does 300 J of work per cycle to extract 2100 J of heat per cycle from a freezer whose temperature is . What is the maximum air temperature for which this condition can be met? Is this a reasonable condition to impose on the design?

Solution

27.5 °C, which is a warm room so it should work

1. A Carnot engine employs 1.5 mol of nitrogen gas as a working substance, which is considered as an ideal diatomic gas with  at the working temperatures of the engine. The Carnot cycle goes in the cycle *ABCDA* with *AB* being an isothermal expansion. The volume at points *A* and *C* of the cycle are  and 0.15 L, respectively. The engine operates between two thermal baths of temperature 500 K and 300 K. (a) Find the values of volume at *B* and *D*. (b) How much heat is absorbed by the gas in the *AB* isothermal expansion? (c) How much work is done by the gas in the *AB* isothermal expansion? (d) How much heat is given up by the gas in the *CD* isothermal expansion? (e) How much work is done by the gas in the *CD* isothermal compression? (f) How much work is done by the gas in the *BC* adiabatic expansion? (g) How much work is done by the gas in the *DA* adiabatic compression? (h) Find the value of efficiency of the engine based on the net work and heat input. Compare this value to the efficiency of a Carnot engine based on the temperatures of the two baths.

Solution

a.  b. 13,000 J; c. 13,000 J; d. –8,000 J; e. –8,000 J; f. 6200 J; g. –6200 J; h. ; with temperatures efficiency is , which is off likely by rounding errors.

1. A 5.0-kg wood block starts with an initial speed of 8.0 m/s and slides across the floor until friction stops it. Estimate the resulting change in entropy of the universe. Assume that everything stays at a room temperature of 20 °C.

Solution

0.55 J/K

1. A system consisting of 20.0 mol of a monoatomic ideal gas is cooled at constant pressure from a volume of 50.0 L to 10.0 L. The initial temperature was 300 K. What is the change in entropy of the gas?

Solution

–670 J/K

1. A glass beaker of mass 400 g contains 500 g of water at 27 °C. The beaker is heated reversibly so that the temperature of the beaker and water rise gradually to 57 °C. Find the change in entropy of the beaker and water together.

Solution

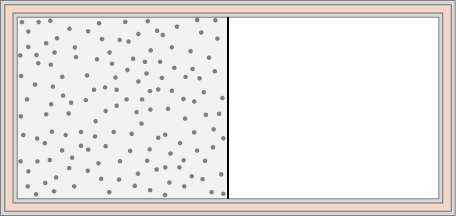
200 J/K

1. A Carnot engine operates between 550 °C and 20 °C baths and produces 300 kJ of energy in each cycle. Find the change in entropy of the (a) hot bath and (b) cold bath, in each Carnot cycle?

Solution

a. –570 J/K; b. 570 J/K

1. An ideal gas at temperature *T* is stored in the left half of an insulating container of volume *V* using a partition of negligible volume (see below). What is the entropy change per mole of the gas in each of the following cases? (a) The partition is suddenly removed and the gas quickly fills the entire container. (b) A tiny hole is punctured in the partition and after a long period, the gas reaches an equilibrium state such that there is no net flow through the hole. (c) The partition is moved very slowly and adiabatically all the way to the right wall so that the gas finally fills the entire container.



Solution

a. 5.8 J/K; b. 5.8 J/K; c. 0

1. A 0.50-kg piece of aluminum at 250 °C is dropped into 1.0 kg of water at 20 °C. After equilibrium is reached, what is the net entropy change of the system?

Solution

82 J/K

1. Suppose 20 g of ice at 0 °C is added to 300 g of water at 60 °C. What is the total change in entropy of the mixture after it reaches thermal equilibrium?

Solution

5.3 J/K

1. A heat engine operates between two temperatures such that the working substance of the engine absorbs 5000 J of heat from the high-temperature bath and discharges 3000 J to the low-temperature bath. The rest of the energy is converted into mechanical energy of the turbine. Find (a) the amount of work produced by the engine and (b) the efficiency of the engine.

Solution

a. 2000 J; b. 

1. A thermal engine produces 4 MJ of electrical energy while operating between two thermal baths of different temperatures. The working substance of the engine discharges 5 MJ of heat to the cold temperature bath. What is the efficiency of the engine?

Solution



1. A coal power plant consumes 100,000 kg of coal per hour and produces 500 MW of power. If the heat of combustion of coal is 30 MJ/kg, what is the efficiency of the power plant?

Solution



1. A Carnot engine operates in a Carnot cycle between a heat source at 550 °C and a heat sink at 20 °C. Find the efficiency of the Carnot engine.

Solution



1. A Carnot engine working between two heat baths of temperatures 600 K and 273 K completes each cycle in 5 sec. In each cycle, the engine absorbs 10 kJ of heat. Find the power of the engine.

Solution

1100 W

1. A Carnot cycle working between 100 °C and 30 °C is used to drive a refrigerator between

–10 °C and 30 °C. How much energy must the Carnot engine produce per second so that the refrigerator is able to discard 10 J of energy per second?

Solution

8.1 J

**Challenge Problems**

1. (a) An infinitesimal amount of heat is added reversibly to a system. By combining the first and second laws, show that . (b) When heat is added to an ideal gas, its temperature and volume change from . Show that the entropy change of *n* moles of the gas is given by



Solution

derive

1. Using the result of the preceding problem, show that for an ideal gas undergoing an adiabatic process, is constant.

Solution

derive

1. With the help of the two preceding problems, show that  between states 1 and 2 of *n* moles an ideal gas is given by



Solution

derive

1. A cylinder contains 500 g of helium at 120 atm and 20 °C. The valve is leaky, and all the gas slowly escapes isothermally into the atmosphere. Use the results of the preceding problem to determine the resulting change in entropy of the universe.

Solution

–4970 J/K

1. A diatomic ideal gas is brought from an initial equilibrium state at  and  to a final stage with  and  Use the results of the previous problem to determine the entropy change per mole of the gas.

Solution

18 J/K

1. The gasoline internal combustion engine operates in a cycle consisting of six parts. Four of these parts involve, among other things, friction, heat exchange through finite temperature differences, and accelerations of the piston; it is irreversible. Nevertheless, it is represented by the ideal reversible *Otto cycle*, which is illustrated below. The working substance of the cycle is assumed to be air. The six steps of the Otto cycle are as follows:
2. Isobaric intake stroke (*OA*). A mixture of gasoline and air is drawn into the combustion chamber at atmospheric pressure *p*0 as the piston expands, increasing the volume of the cylinder from zero to .
3. Adiabatic compression stroke (*AB*). The temperature of the mixture rises as the piston compresses it adiabatically from a volume .
4. Ignition at constant volume (*BC*). The mixture is ignited by a spark. The combustion happens so fast that there is essentially no motion of the piston. During this process, the added heat  causes the pressure to increase from  at the constant volume .
5. Adiabatic expansion (*CD*). The heated mixture of gasoline and air expands against the piston, increasing the volume from . This is called the *power stroke*, as it is the part of the cycle that delivers most of the power to the crankshaft.
6. Constant-volume exhaust (*DA*). When the exhaust valve opens, some of the combustion products escape. There is almost no movement of the piston during this part of the cycle, so the volume remains constant at . Most of the available energy is lost here, as represented by the heat exhaust .
7. Isobaric compression (*AO*). The exhaust valve remains open, and the compression from  to zero drives out the remaining combustion products.
8. Using (*i*) ; (*ii*) ; and (*iii*) , , show that

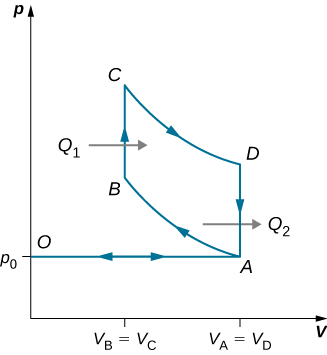
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1. Use the fact that steps (ii) and (iv) are adiabatic to show that

,

where . The quantity *r* is called the *compression ratio* of the engine.

1. In practice, *r* is kept less than around 7. For larger values, the gasoline-air mixture is compressed to temperatures so high that it explodes before the finely timed spark is delivered. This *preignition* causes engine knock and loss of power. Show that for  and  (the value for air), , or an efficiency of . Because of the many irreversible processes, an actual internal combustion engine has an efficiency much less than this ideal value. A typical efficiency for a tuned engine is about .



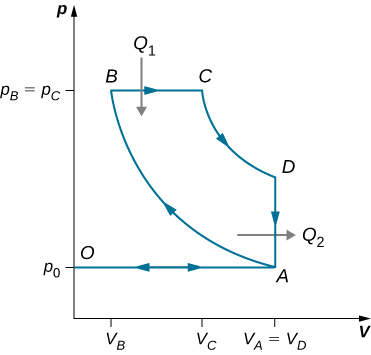
Solution

proofs

1. An ideal *diesel* cycle is shown below. This cycle consists of five strokes. In this case, only air is drawn into the chamber during the intake stroke *OA*. The air is then compressed adiabatically from state *A* to state *B*, raising its temperature high enough so that when fuel is added during the power stroke *BC*, it ignites. After ignition ends at *C*, there is a further adiabatic power stroke *CD*. Finally, there is an exhaust at constant volume as the pressure drops from  to , followed by a further exhaust when the piston compresses the chamber volume to zero.
2. Use , , and  to show that.
3. Use the fact that  and  are adiabatic to show that

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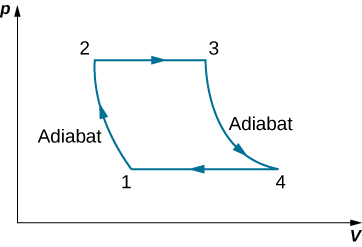
1. Since there is no preignition (remember, the chamber does not contain any fuel during the compression), the compression ratio can be larger than that for a gasoline engine. Typically, . For these values and  show that , or an efficiency of . Diesel engines actually operate at an efficiency of about  compared with  for gasoline engines.



Solution

proof

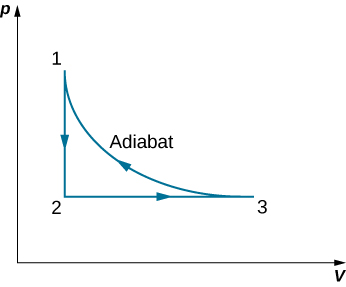
1. Consider an ideal gas Joule cycle, also called the Brayton cycle, shown below. Find the formula for efficiency of the engine using this cycle in terms of , , and .



Solution



1. Derive a formula for the coefficient of performance of a refrigerator using an ideal gas as a working substance operating in the cycle shown below in terms of the properties of the three states labeled 1, 2, and 3.



Solution



1. Two moles of nitrogen gas, with  for ideal diatomic gases, occupies a volume of  in an insulated cylinder at temperature 300 K. The gas is adiabatically and reversibly compressed to a volume of 5 L. The piston of the cylinder is locked in its place, and the insulation around the cylinder is removed. The heat-conducting cylinder is then placed in a 300-K bath. Heat from the compressed gas leaves the gas, and the temperature of the gas becomes 300 K again. The gas is then slowly expanded at the fixed temperature 300 K until the volume of the gas becomes , thus making a complete cycle for the gas. For the entire cycle, calculate (a) the work done by the gas, (b) the heat into or out of the gas, (c) the change in the internal energy of the gas, and (d) the change in entropy of the gas.

Solution

a. and b. ; c. ; d. 

1. A Carnot refrigerator, working between 0 °C and 30 °C is used to cool a bucket of water containing  of water at 30 °C to 5 °C in 2 hours. Find the total amount of work needed.

Solution



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