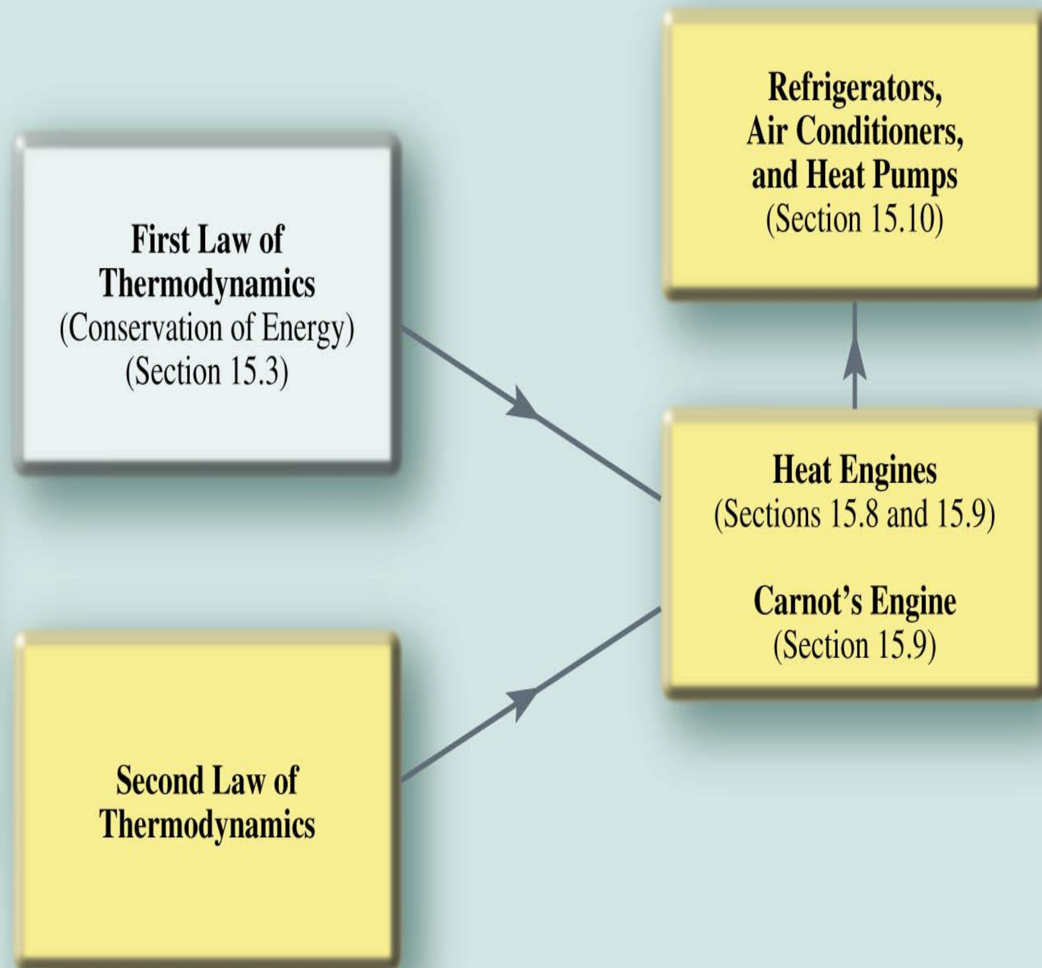
The Second Law of Thermodynamics

THE SECOND LAW OF THERMODYNAMICS:
THE HEAT FLOW STATEMENT

Heat flows spontaneously from a substance at a higher temperature to a substance at a lower temperature and does not flow spontaneously in the reverse direction.

CONCEPTS AT A GLANCE



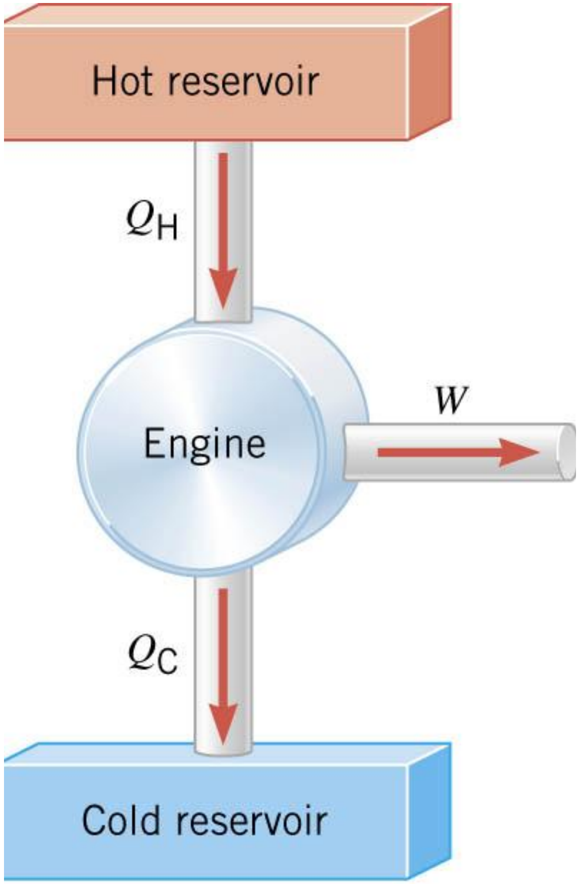
Heat Engines

A *heat engine* is any device that uses heat to perform work. It has three essential features:

1.Heat is supplied to the engine at a relatively high input temperature from a place called the *hot reservoir*.

2.Part of the input heat is used to perform work by the *working substance* of the engine, which is the material within the engine that actually does the work (e.g., the gasoline-air mixture in an automobile engine).

3.The remainder of the input heat is rejected to a place called the *cold reservoir*, which has a temperature lower than the input temperature.



These three symbols refer to magnitudes only, without reference to algebraic signs. Therefore, when these symbols appear in an equation, they do not have negative values assigned to them.

$$e = \frac{\text{Work done}}{\text{Input heat}} = \frac{W}{Q_H}$$

Efficiencies are often quoted as percentages obtained by multiplying the ratio W/QH by a factor of 100.

$$Q_H = W + Q_C$$

$$e = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

Example 6. An Automobile Engine

An automobile engine has an efficiency of 22.0% and produces 2510 J of work. How much heat is rejected by the engine?

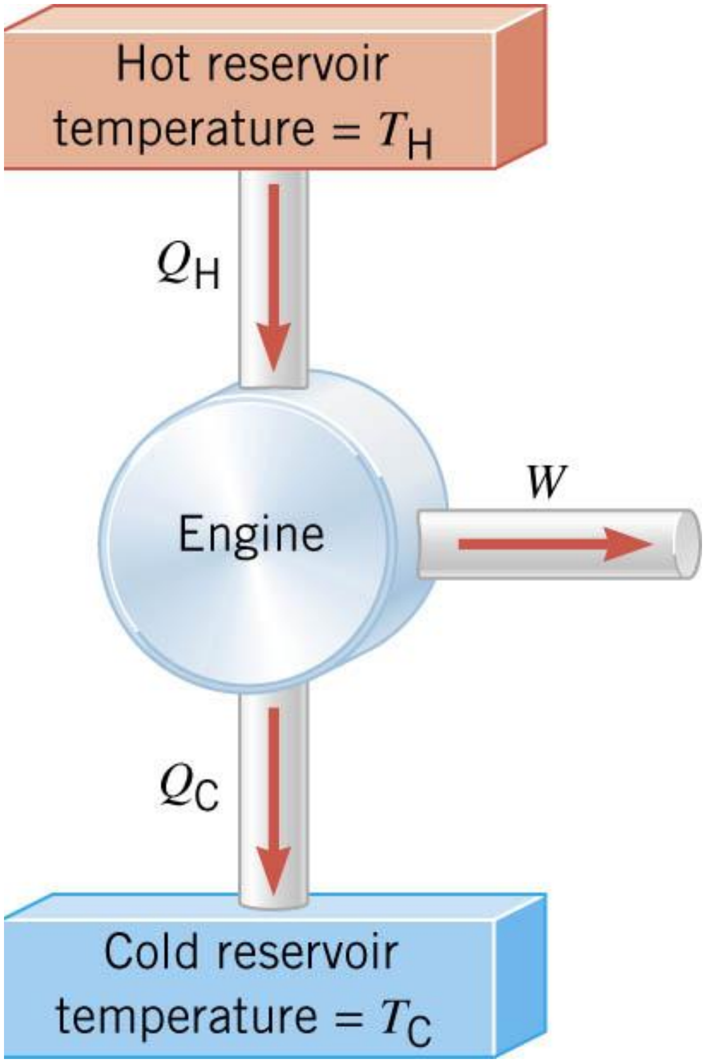
$$Q_C = Q_H - W = \frac{W}{e} - W = (2510\,\text{J})\left(\frac{1}{0.220} - 1\right) = \boxed{8900\,\text{J}}$$

Carnot's Principle and the Carnot Engine

A reversible process is one in which both the system and its environment can be returned to exactly the states they were in before the process occurred.

CARNOT'S PRINCIPLE: AN ALTERNATIVE STATEMENT OF THE SECOND LAW OF THERMODYNAMICS

No irreversible engine operating between two reservoirs at constant temperatures can have a greater efficiency than a reversible engine operating between the same temperatures. Furthermore, all reversible engines operating between the same temperatures have the same efficiency.



A *Carnot engine* is a reversible engine in which all input heat Q_H originates from a hot reservoir at a single temperature *T*H, and all rejected heat Q_C goes into a cold reservoir at a single temperature T_C. The work done by the engine is *W*.

$$\frac{Q_C}{Q_H} = \frac{T_C}{T_H}$$

where the temperatures T_C and T_H ***must be expressed in kelvins*** **.**

$$\text{Efficiency of a Carnot engine} = e_{\text{Carnot}} = 1 - \frac{T_C}{T_H}$$

Example 7.
A Tropical Ocean as a Heat Engine

Water near the surface of a tropical ocean has a temperature of 298.2 K (25.0 ° C), whereas water 700 m beneath the surface has a temperature of 280.2 K (7.0 ° C). It has been proposed that the warm water be used as the hot reservoir and the cool water as the cold reservoir of a heat engine. Find the maximum possible efficiency for such an engine.

T_H **= 298.2 K and** T_C **= 280.2 K**

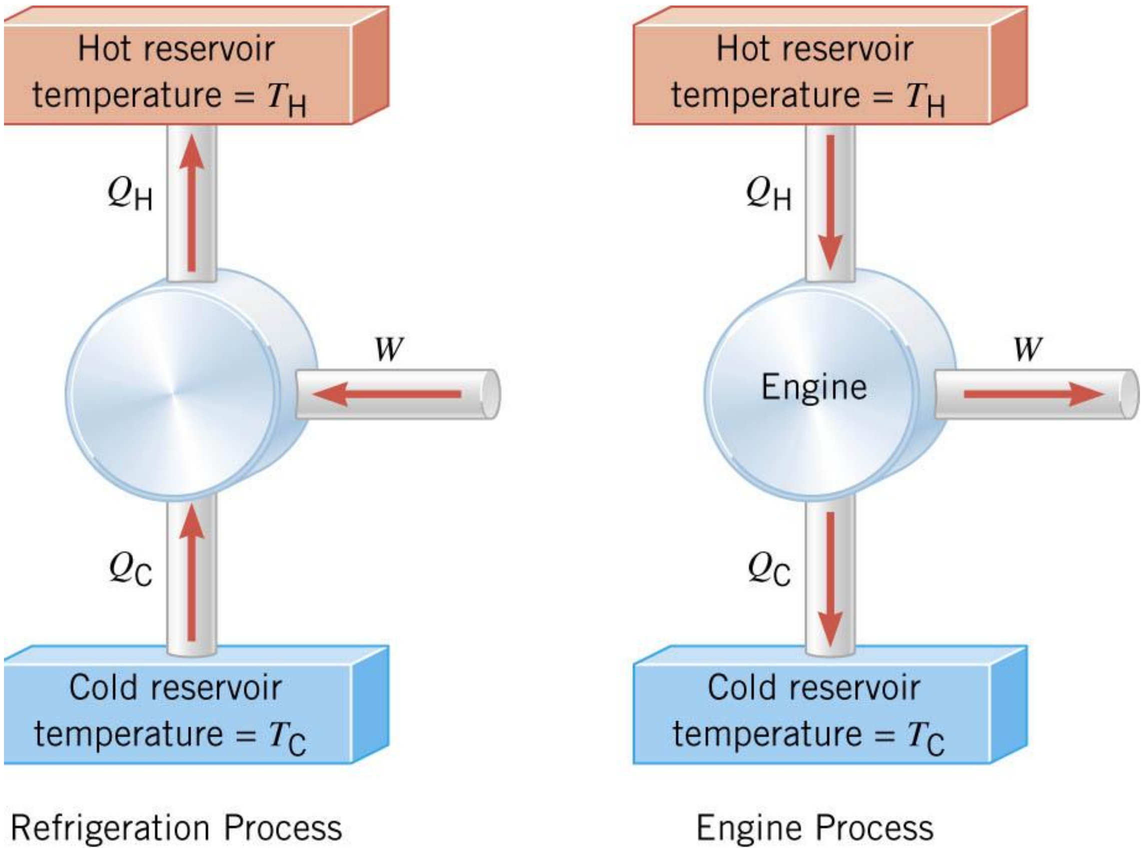
$$e_{Carnot} = 1 - \frac{T_C}{T_H} = 1 - \frac{280.2\,K}{298.2\,K} = \boxed{0.060\ (6.0\%)}$$

Conceptual Example 8. Limits on the Efficiency of a Heat Engine

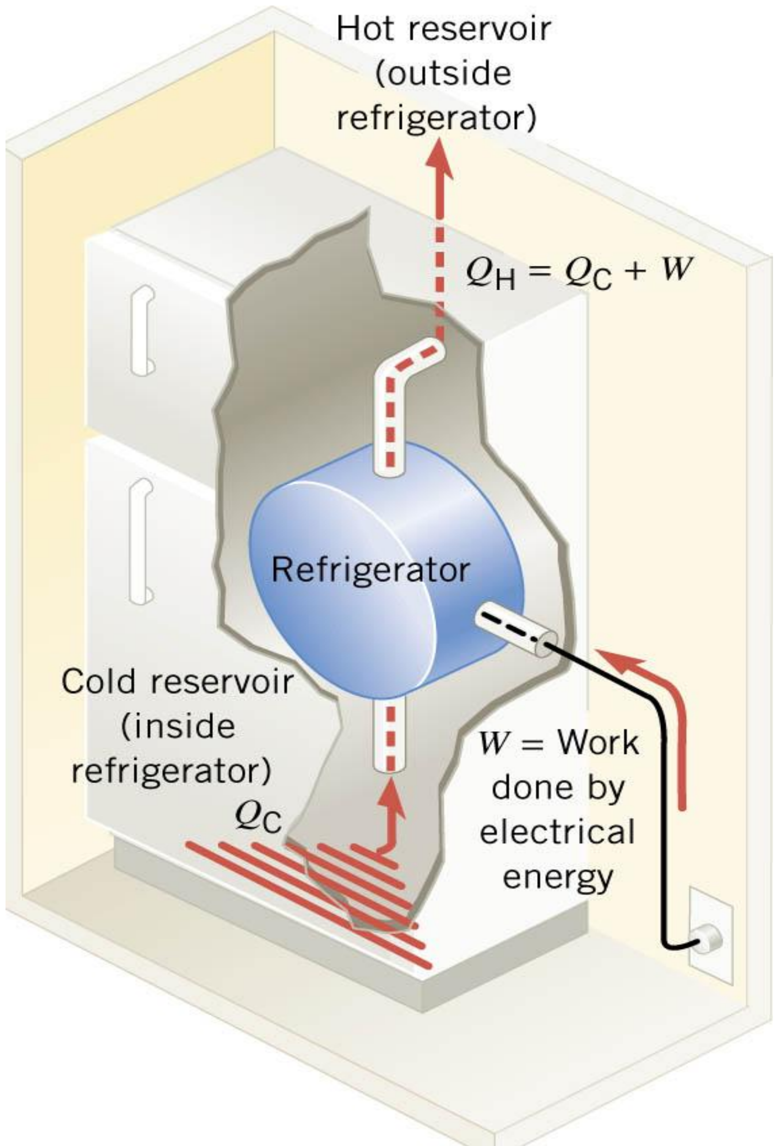
Consider a hypothetical engine that receives 1000 J of heat as input from a hot reservoir and delivers 1000 J of work, rejecting no heat to a cold reservoir whose temperature is above 0 K. Decide whether this engine violates the first or the second law of thermodynamics, or both.

It is the second law, not the first law, that limits the efficiencies of heat engines to values less than 100%.

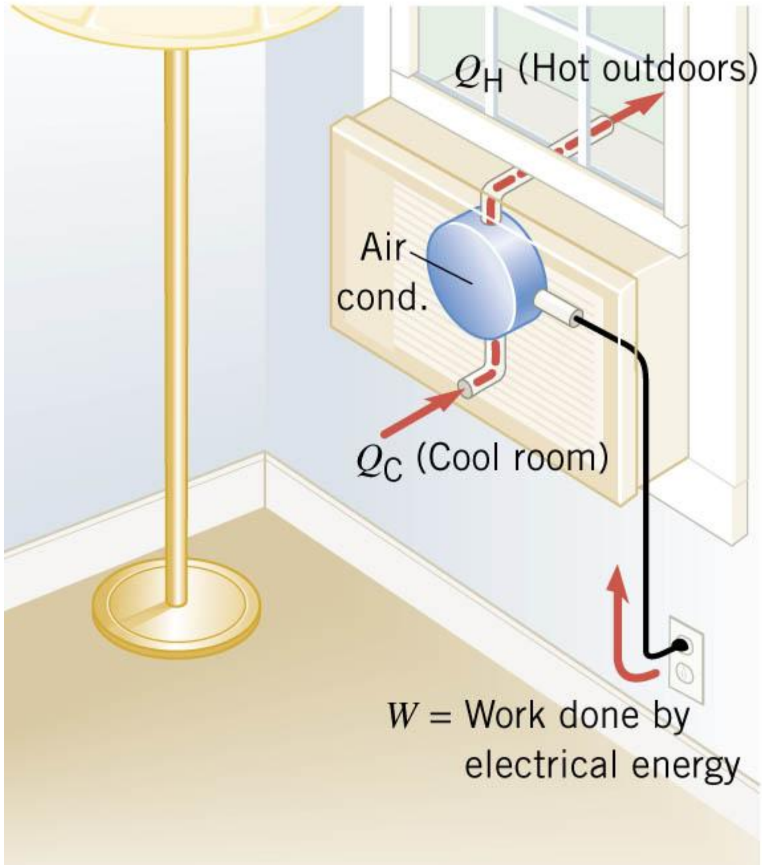
Refrigerators, Air Conditioners, and Heat Pumps



In the refrigeration process, work *W* is used to remove heat Q_C from the cold reservoir and deposit heat Q_H into the hot reservoir.



In a *refrigerator,* the interior of the unit is the cold reservoir, while the warmer exterior is the hot reservoir.



A window air conditioner removes heat from a room, which is the cold reservoir, and deposits heat outdoors, which is the hot reservoir.

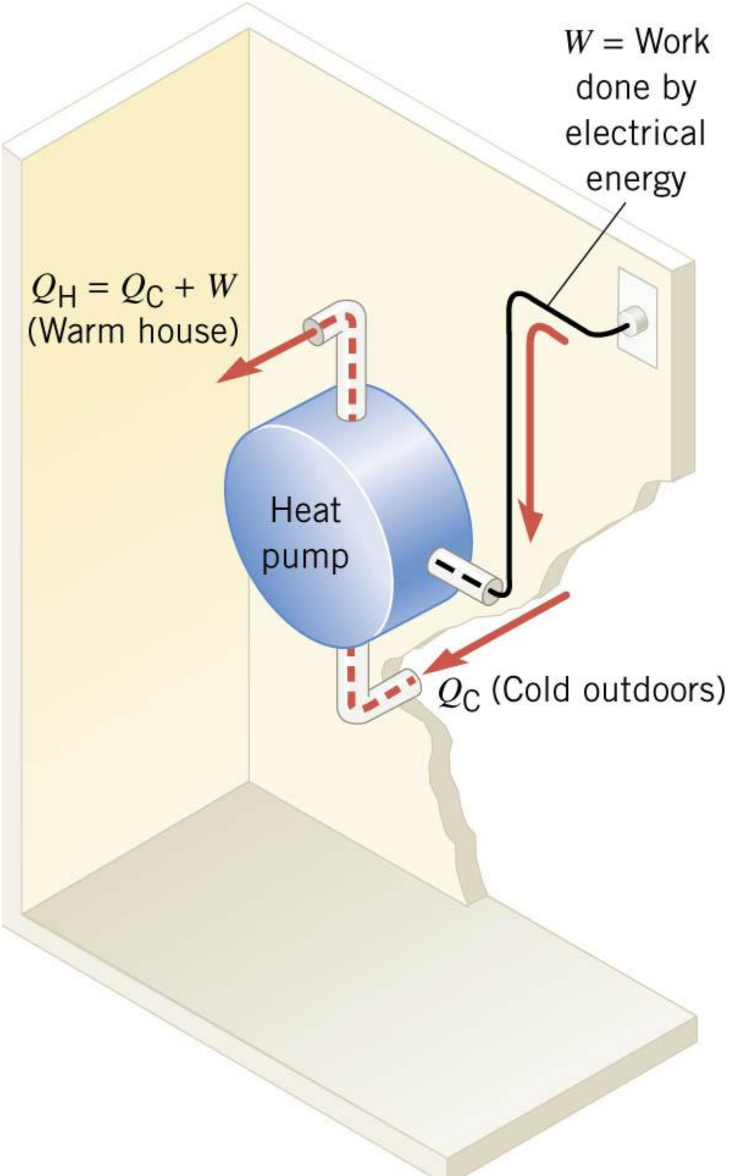
Conceptual Example 9. You Can't Beat the Second Law of Thermodynamics

Is it possible to cool your kitchen by leaving the refrigerator door open or cool your bedroom by putting a window air conditioner on the floor by the bed?

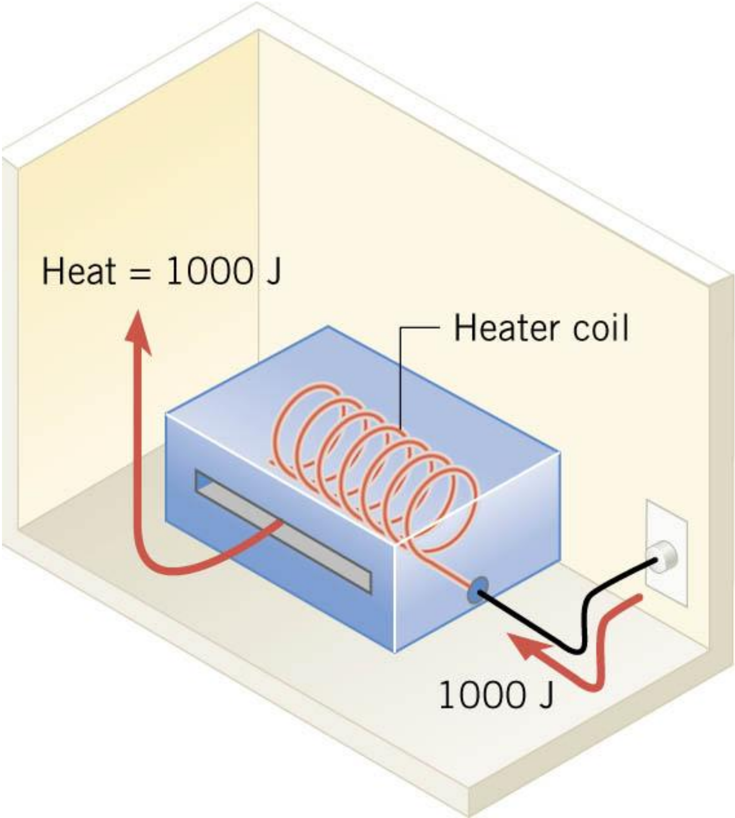
Rather than cooling the kitchen, the open refrigerator warms it up. The air conditioner actually warms the bedroom.

Refrigerator or air conditioner

$$\text{Coefficient of performance} = \frac{Q_C}{W}$$



In a heat pump the cold reservoir is the wintry outdoors, and the hot reservoir is the inside of the house.



This conventional electric heating system is delivering 1000 J of heat to the living room.

$$Q_H = W + Q_C \text{ and } Q_C/Q_H = T_C/T_H$$

Example 10. A Heat Pump

An ideal or Carnot heat pump is used to heat a house to a temperature of T_H = 294 K (21 ° C). How much work must be done by the pump to deliver Q_H = 3350 J of heat into the house when the outdoor temperature T_C is (a) 273 K (0 ° C) and (b) 252 K (–21 ° C)?

$$W = Q_H - Q_C = Q_H - Q_H\left(\frac{T_C}{T_H}\right) = Q_H\left(1 - \frac{T_C}{T_H}\right)$$

(a) $$W = Q_H\left(1 - \frac{T_C}{T_H}\right) = (3350\,\text{J})\left(1 - \frac{273\,\text{K}}{294\,\text{K}}\right) = \boxed{240\,\text{J}}$$

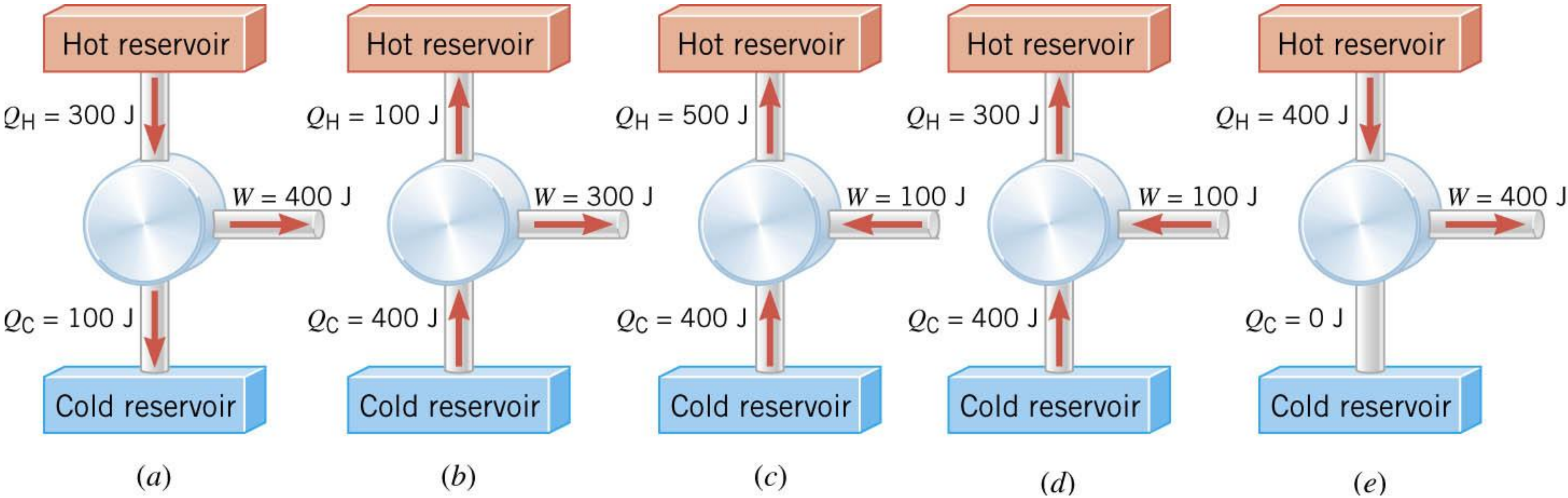
(b) $$W = \boxed{479\,\text{J}}$$

Heat pump

$$\text{Coefficent of performance} = \frac{Q_H}{W}$$

Check Your Understanding 3

Each drawing represents a hypothetical heat engine or a hypothetical heat pump and shows the corresponding heats and work. Only one is allowed in nature. Which is it?



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