**f.** What would happen to the engine on a very hot day when the temperature inside the factory was as hot as the heated air coming from the hair dryer or heat gun?

**g.** Suppose that all the thermal energy given off by the hair dryer is absorbed by the rubber band. Does it appear likely that our rubber band lifter converts *all* of the thermal energy it absorbs from the hair dryer into useful mechanical work (that is, work done lifting cans)? Does any of that absorbed thermal energy have to go elsewhere? **Hint:** What has to happen to the rubber band after the lifted can is taken away but before it can pick up a new can from the lower belt?

---

## 18.8. ENERGY FLOW DIAGRAMS, CYCLES, AND EFFICIENCY

One of the key features of our rubber band engine is that to be ready to lift the next can, the rubber band must cool by giving off thermal energy to its surroundings, which are colder than the hot air from the hair dryer. After the rubber band has cooled and stretched back to its original shape, it is in the same *thermodynamic state* that it was in at the start; that is, all its properties, including its internal energy, $E^{int}$, are the same. *For one complete cycle of our rubber band engine* $\Delta E^{int} = 0$ J.

If $Q_{hot}$ is the thermal energy absorbed by the rubber band from the air heated by the hair dryer and $Q_{cold}$ is the thermal energy transferred to the cooler room air, the net thermal energy absorbed in the cycle is $Q = Q_{hot} - |Q_{cold}|$ and the first law of thermodynamics becomes

$$\Delta E^{int} = Q - W = \left(Q_{hot} - |Q_{cold}|\right) - W \qquad (18.3)$$

Since $\Delta E^{int} = 0$ J for our *complete* cycle, we can simplify this by writing:

$$W = Q_{hot} - |Q_{cold}|$$

### The Carnot Engine

As noted by Sadi Carnot in 1824, all heat engines have this characteristic: the performance of useful work is accompanied by thermal energy being transferred to the working medium from a hot body and some thermal energy subsequently being transferred to a cooler body. The difference between these thermal energies constitutes the useful work that can be done by the cycle. The hot body is usually called the *high temperature reservoir* and the cool body is the *low temperature reservoir*. The word reservoir is used because we imagine that we have so much matter that we can transfer an amount of thermal energy, $Q_{hot}$, from the hot reservoir or dump thermal energy, $Q_{cold}$, to the cold reservoir without changing their temperatures measurably.

This basic fact about heat engines is often discussed in terms of an energy flow diagram such as the one shown below. This diagram would work equally well for an old-fashioned steam engine or our rubber band can lifter.

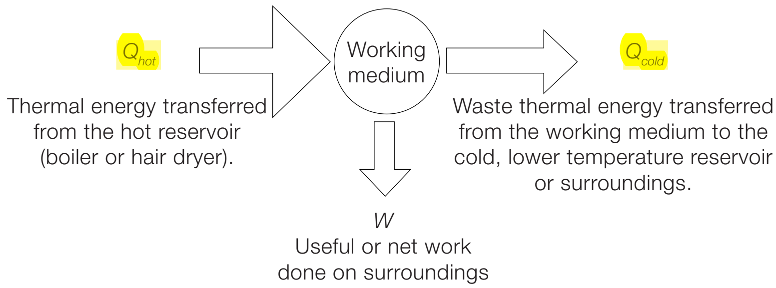


**Fig. 18.6.** Heat engine schematic.

Figure 18.6 is a pictorial representation of what we have written in words: our engine has thermal energy $Q_{hot}$ transferred to it, does work $W$, and transfers some of the original thermal energy $Q_{cold}$ to lower temperature surroundings.

We can define the efficiency of any engine cycle as the desired amount of work produced as a result of the cycle (in this case the useful or net work done) divided by the magnitude of the thermal energy that must be transferred to the working medium to achieve the result (in this case the $|Q_{hot}|$ absorbed from the hair dryer). The efficiency of a heat engine is usually denoted as $\eta$ ("eta"). In defining efficiency physicists often put bars around the symbols for thermal energy and work to designate that it is the magnitude of energy being transferred in or out of the system that is to be used in equations for efficiency.

### 18.8.1. Activity: Defining Efficiency

**a.** Use the definition of efficiency to write the equation for engine efficiency, $\eta$, in terms of the magnitude of the net work done, $|W|$, and the magnitude of the thermal energy transferred to the working medium from the hot reservoir, $|Q_{hot}|$.

**b.** Use the first law of thermodynamics and the fact that after completion of a full engine cycle the net change in the internal energy of the working medium is zero to show that

$$\eta = 1 - \frac{|Q_{cold}|}{|Q_{hot}|} \qquad (18.4)$$

**Hint:** $W \equiv |Q_{hot}| - |Q_{cold}|$ where $|Q_{cold}|$ is the magnitude of the waste thermal energy transferred to the cold reservoir during the cycle.