# AP Physics - Heat Engines

Heat engines operate by converting heat into work. Examples of heat engines abound - abound! Says the Physics Kahuna - all around us. Gasoline engines, jet engines, diesel engines, and steam engines. Just about anything that burns fuel to generate heat is a heat engine. You could be considered to be a low-tech heat engine (but a really nice one, I’m sure we all agree).



Heat is added to the engine at a high temperature. Part of the heat is used to generate work and the rest of the heat is sent to some low temperature environment.

Fancy terminology used for heat engines involves things like: ***high temperature heat reservoir*** (the source of the input heat), ***low temperature heat reservoir*** (where you send the heat you don’t use) – sometimes this is called the ***low temperature heat sink***.

For a great many heat engines, the heat sink will be the atmosphere – think of a gasoline car engine. Stationary electric power plants might use water from a river. A steam ship would use the sea, and so on.

Most engines have a cyclic operation – steps that are repeated over and over in order to do the work. A car engine has pistons that repeatedly move up and down producing power from the motion of the piston.

***Efficiency:*** The heat that is not converted to work is called the ***waste heat***. All heat engines produce waste heat. The waste heat is sent to the heat sink. The first law tells us that the engine can never produce more work than the heat that went into it. After all, energy has to be conserved, correct?

The ratio of output work to input work/energy is called efficiency.

 This is written as  for the AP Physics Test.

This simply says that the efficiency is the absolute value of the ratio of output work to input heat.

The first law says that the efficiency cannot be greater than one. But we’ve already said that some of the input heat does not become work. Doesn’t this mean that the efficiency has to be less than one? Well, so it is.

This was discovered in 1824 by Sadi Carnot (actually Nicolas-Leonard-Sadi Carnot – he had a lot of names for a French physicist). If an engine couldn’t be one hundred percent efficient, what was the best you could do? Carnot set out to find the answer to that question. In his pursuit, he invented thermodynamics.

Carnot imagined the best possible engine, this would be an ideal engine – it wouldn’t have friction between its moving parts and it wouldn’t lose heat through the walls of its cylinders, etc. An ideal engine would have no change in its internal energy. For the engine:

  so 

The work done by this ideal engine is simply equal to the change in heat, ***ΔQ***.

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 ***QH*** is the high temperature and ***QC*** is the low temperature.

We plug this into the efficiency equation (for like one cycle):

 

 Plug in value for work we figured out:

 But ***Qin*** is simply ***QH***.

 

Lord Kelvin changed Carnot’s interpretation of efficient based on the fact that Q is proportional to T so:

 

This is the efficiency of an ideal energy. It is the best efficiency that it is possible to obtain.



***The temperatures must be in Kelvins!***

No real engine can achieve this efficiency, but it is possible to come close. The equation is important because it shows us that the efficiency depends on the two temperature extremes used by the engine. The higher the temperature the engine operates at and the lower the temperature of the heat reservoir, the higher the efficiency will be.

Diesel engines are more efficient than gasoline engines because they operate at a higher temperature.

It is expensive to build machines that can operate at high temperatures – you need costly metal alloys that can handle the temperature, the engine must be stronger because it is doing more work, so its components have to be beefed up, and so on. Engine designers have to balance tradeoffs like that between efficiency and manufacturing expense.

Q: A steam engine operates on a warm 28.0 °C day. The saturated steam operates at a temperature of 100.0 °C. What is the ideal efficiency for this engine?

ANS: 0.193 or 19.3%