Carnot cycle first law of thermodynamics

Previous index next Michael Fowler The laws of thermodynamics (pictured below of St. Andrews) in 1850, Rudolph Clausius, a German physicist, created the science of thermodynamics. He was convinced of Joule's experiments (he knew nothing about Mayer's work at the time) that the total energy, including kinetic, potential, electric and above all heat, was preserved, he called it: The first law of thermodynamics: Total energy, including heat energy, is always conserved. He explicitly assumed that heat was only the kinetic energy of the moving particles that made up a body. He was the first to make it clear that Carnot's analysis of the heat engine (the cycle) was almost correct, except that the caloric liquid, i.e. heat, was not really preserved – less of it was tipped into the cold reservoir than was taken from the hot one. The difference, of course, was the work done (in an ideal engine). Engines were so inefficient at the time that this heat loss was not obvious. But the abolition of calorie fluid in favour of general energy saving raised another problem. Flow theory was very successful in describing heat flux by solid materials, such as electric current flow, but with temperature gradients that replace voltage drops, different materials with different thermal conductivity, etc. (Note: Fourier revolutionized mathematics by inventing Fourier series, his method of analyzing the calorie-rich fluid flow. In fact, Kelvin used it in 1862 to estimate the Earth's cooling rate. Kelvin's conclusion that the Earth was about twenty million years old (much colder would be much colder) led to decades of debate with Darwinians and geologists, both of whom needed much more time to form evolutionary or rock layers. The debate lasted until the 1890s, when the discovery of radioactivity made it clear that this unprecedented source of subterranean heat kept us all warm. Once this extra heat was included, the heat flux analysis gave a much older earth – and everyone agreed.) In calorie theory, the heat naturally flowed from a high temperature to a low temperature, just as a liquid goes downhill or an electric current flows to a lower voltage. And of course, this heat flux is observed in nature without exception. But the first law makes no such prediction: the saving of total energy would be just as satisfying if heat flowed from a cold body to a hot body. Conclusion: Since calorie theory is dead, we need to add this generally observed direction of heat flux as another law. Here it is: The Law of thermodynamics: Heat always flows from a warm body to a cooler, never reversed. An equivalent statement is that we cannot develop an engine that operates in a cycle that causes heat to flow from cold to warm, unless we supply external energy. Energy. Your fridge won't work if it's not connected to a power supply, and no one will ever design one to do so. In contrast to the first law, there are many ways to write this Second Law: our above formulation is a paraphrase of Clausius's original formulation. Kelvin gave him a more engineering look: it is impossible to develop an engine that, working in a cycle, must produce no other effect than the extraction of heat from a reservoir and the performance of an equal amount of mechanical work. Exercise: Think about how you could prove these two definitions, which are the same. The Second Law can also be related to entropy, a concept that we will discuss in the next lecture. It is important to note that the first law of thermodynamics, the saving of total energy including heat, would not be violated by an engine that drives a ship by extracting heat energy from the surrounding seawater. This second law says something new: you can't do that! And this Second Law does not follow from the first by logical derivation – it comes (like the first) from experiment ation and observation. As the second law limits the efficiency of the engine An important consequence of the Second Law is that no engine can be more efficient than the Carnot cycle. Essentially, this is because a super-efficient engine, if it existed, could be used to reverse a carnot cycle that would pump the heat that the super-efficient engine has offloaded in the refrigerated storage tank back into the hot tank, and the net effect of the two coupled engines would be to take heat from the hot reservoir and do work, which is contrary to the Second Law. To see this, we record the heat/energy flow for the Carnot cycle: Here Q H = Q C +W (of course all expressed in joules). Since the engine is reversible, it can also run backwards (that would be a refrigerator): outdoor work is delivered, and heat is taken from a cold reservoir and tipped into a hot reservoir: Suppose we now have a super-efficient engine, represented by the first diagram above, and throw the same heat per cycle Q C into the cooling reservoir, but to take more heat energy q H + Joules from the hot reservoir, and to do more work: W+. Now we connect our super-efficient engine to the Carnot refrigerator in the other diagram above. The refrigerator sucks all the heat that the super-efficient engine has offloaded there from the cold reservoir and needs W Joule's work per cycle to do it. The super-efficient engine can offer this, and there is still a lot of work to be done. Of course, the Carnot refrigerator also has Q H Joule of heat in the hot Tilted. But the bottom line is that the super-efficient engine and the Carnot refrigerator between them have extracted joules of heat from the hot reservoir and done the work – contrary to the Second Law. that the The law therefore forces the conclusion that no amount of machine design will produce an engine more efficiently than the Carnot cycle. The rather low ultimate efficiencies dictated by this diktat were a shock to 19th-century engineers. Exercise: Prove that it is impossible to construct a reversible motor that works between two temperatures that is less efficient than the Carnot cycle. (Note: Hook it to a carnot cycle, drive one backwards.) It follows that although we used an ideal gas in our analysis, it was unnecessary – the same efficiency would result in any reversible engine working between the same two temperatures. as a result of the EU General Data Protection Regulation (GDPR). We currently do not allow Internet traffic on byjus website from countries within the European Union. No tracking or performance measurement cookies have been provided on this page. In the early 19th century, steam engines played an increasingly important role in industry and transport. However, a systematic theory of the conversion of thermal energy into driving power by steam engines had not yet been developed. Nicolas Léonard Sadi Carnot (1796-1832), French military engineer, published Reflections on the Motive Power of Fire in 1824. The book proposed a generalized theory of heat motors and an idealized model of a thermodynamic system for a heat engine now known as the Carnot cycle. Carnot developed the basis of the second law of thermodynamics and is often referred to as the father of thermodynamics. The Carnot cycle consists of the following four processes: a reversible isothermal gas expansion process. The ideal gas in the system q_ absorbs the amount of heat from a heat source at a high temperature (T_,-high), expands and works on the environment. A reversible adiabatic gas expansion process. The system is thermally insulated. The gas continues to expand and work on the environment, cooling the system to a lower temperature, as T_. A reversible isothermal gas compression process. In this process, the environment works on the gas at T_) and causes heat loss, e.B. q_. A reversible adiabatic gas compression process. The system is thermally insulated. The environment continues to work on the gas, bringing the temperature back to the temperature T_. Figure :('PageIndex{1}'): An ideal gas-piston model of the Carnot cycle. The P-V chart of the Carnot cycle is shown in the PageIndex{2} figure. In isothermal processes I and III ΔU=0 because ΔT=0. In adiabatic processes II and IV, q=0. Work, heat, ΔU and ΔH of each process in the Carnot cycle are displayed in the table Summarized. Figure :('PageIndex{2}'): A P-V chart of the Carnot cycle. Table :('PageIndex{1}'): work, work, and ΔH in the P-V diagram of the Carnot cycle. Process w q 'U'H'H'nRT_'T_ C_ T_ T_ C_ V_{1} V_{2} nRT_ V_{1} V_{2}'low-T_-high))) (nbar, C_p(T_,-T_-High)) III ,(-nRT_-nRT_--C_ V_{3} V_{4} nRT_ V_{3} V_{4}v-T_-High-T_-low) 0 (n,C_,-v) (T_-Hight-T_--Low-)) ((n-bar,C_-p-(T_-high-T_-low nRT_ V_{1} V_{2} nRT_)) (Δ nRT_ V_{1} V_{2} nRT_ V_{3} V_{4} In the adiabatic processes II and IV ΔS=0, because dq=0. ΔT and ΔS of each process in the Carnot cycle are displayed in the PageIndex{2} table. Figure :('PageIndex{3}'): A T-S chart of the Carnot cycle. PageIndex{1} table: Work, heat, and ΔU in the T-S chart of the Carnot cycle. Process :,T'S'S'0'V_{3} V_{4} T_ T_ V_{1} V_{2}'IV (T_-high-T_-low) 0 Full cycle 0 0 The Carnot cycle is the most efficient motor based on the assumption that there are no random wasteful processes such as friction and the assumption that there is no heat conduction between different parts of the engine at different temperatures. The efficiency of the Carnot motor is defined as the ratio of energy output to energy input. \[\begin{align*} \text{efficiency} &=\dfrac{\text{net work done by heat engine}}{\text{heat absorbed by heat engine}} =\dfrac{-w_{sys}}{q_{high}} \\[4pt] &=\dfrac{nRT_{high}\ln\left(\dfrac{V_{2}}{V_{1}}\right)+nRT_{low}\ln \left(\dfrac{V_{4}}{V_{3}}\right)}{nRT_{high}\ln\left(\dfrac{V_{2}}{V_{1}}\right)} \end{align*}\] Since processes II (2-3) and IV (4-1) are adiabatic, \[\left(\dfrac{T_{2}}{T_{3}}\right)^{C_{V}/R}=\dfrac{V_{3}}{V_{2}}\] and \[\left(\dfrac{T_{1}}{T_{4}}\right)^{C_{V}/R}=\dfrac{V_{4}}{V_{1}}\] And since T1 = T2 and T3 = T4, \[\dfrac{V_{3}}{V_{4}}=\dfrac{V_{2}}{V_{1}}\] Therefore, \[\text{efficiency}=\dfrac{nRT_{high}\ln\left(\dfrac{V_{2}}{V_{1}}\right)-nRT_{low}\ln\left(\dfrac{V_{2}}{V_{1}}\right)} {nRT_{high}\ln\left(\dfrac{V_{2}}{V_{1}}\right)}\] \[\boxed{\text{efficiency}=\dfrac{T_{high}-T_{low}}{T_{high}}}\] The Carnot cycle has the greatest efficiency of an engine (although other cycles have the same efficiency) based on the assumption of the absence of random wasteful processes such as friction, and the assumption that no heat conduction between different parts of the engine at different temperatures. Problems You are now operating a Carnot engine with 40% efficiency, which into a heat sink at 298 K. If you want to increase the efficiency of the engine to 65%, to what temperature would you have to raise the heat reservoir? A Carnot motor absorbed 1.0 kJ of heat at 300 K and depleted 400 J heat at the end of the cycle. What is the temperature at the end of the cycle? An indoor heating system operated on the Carnot cycle heats the house at a rate of 30 kJ/s to keep the internal temperature at 72 oF. What is the power that the heating system operates when the outside temperature is 30 oF? References Goldstein, M. J. Chem. Educ., 1980, 57, 114-116 Bader, M. J. Chem. Educ., 1973, 50, 834 W. F. Luder. J. Chem. Educ., 1944, 21, 600-601 Salter, C. J. Chem. Educ., 2000, 77, 1027-1030 Contributors and Attributions Attributions