Self- Assessment Before and After Facilitating Session.
Topic: Heat Engines & Carnot Engines :

Thermal Physics PHY630
Facilitators's Name: ____________________
Your Name: ___________________________

Name: ____
Self Assessment - Preparatory

	Please use the following codes and please mark your selection. **1=- Strongly Disagree: 2=Disagree 3 = Unsure/Undecided 4=Agree 5 = Strongly Agree**	Before peer teaching						After peer teaching				
		SD				SA		SD				SA
1.	I have read the chapter before coming to the discussion session today.	1	2	3	4	5		1	2	3	4	5
2.	I realize that I can write all the expressions for the first law in units of kilojoule, kilowatts or kilojoule per kilogram. Hence the energy balance can be expressed as $\frac{\text{Energy gain}}{\text{by a system}} - \frac{\text{Energy lost}}{\text{by a system}} = \frac{\text{Total energy change}}{\text{within the system}}$. Or mathematically, $E_{in} - E_{out} = \Delta E_{sys}$ in kJ, or $\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys}$, in kW, or $e_{in} - e_{out} = \Delta e_{sys}$ in kJ/kg. Alternatively, it can written as $(Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,in} - E_{mass,out}) = \Delta U + \Delta KE + \Delta PE$ in kJ or $\left(\dot{Q}_{in} - \dot{Q}_{out}\right) + \left(\dot{W}_{in} - \dot{W}_{out}\right) + \left(\dot{E}_{mass,in} - \dot{E}_{mass,out}\right) = \Delta \dot{U} + \Delta \dot{KE} + \Delta \dot{PE}$ in kW or $(q_{in} - q_{out}) + (w_{in} - w_{out}) + (J_{mass,in} - J_{mass,out}) = \Delta u + \Delta ke + \Delta pe$.	1	2	3	4	5		1	2	3	4	5
3.	Hence, for a stationary closed system, the first law of thermodynamics energy balance can be written in any of the following ways: $(Q_{in} - Q_{out}) + (W_{in} - W_{out}) = \Delta U$ or $\left(\dot{Q}_{in} - \dot{Q}_{out}\right) + \left(\dot{W}_{in} - \dot{W}_{out}\right) = \Delta \dot{U}$ or $(q_{in} - q_{out}) + (w_{in} - w_{out}) = \Delta u$.	1	2	3	4	5		1	2	3	4	5
4.	I know that for a stationary-closed system undergoing a cyclic (starts and end at the same state) process, the total energy for the final and initial states are the same, hence **$\Delta E_{sys} = \Delta U = 0$**. Due to this, the energy balance can be written as $(Q_{in} - Q_{out}) + (W_{in} - W_{out}) = 0$. This means that $Q_{in} - Q_{out} = W_{out} - W_{in}$. The physical interpretation of this is very significant since many engineering devices operate in a cycle. This expression clearly indicates that if the left side of the expression is positive then the right side must also be positive and vice-versa. In other words, for a system such as water in a turbine *to produce work and hence electricity*, a net amount of heat must be transferred to the system $(Q_{in} >> Q_{out})$. On the other hand, i*n order to have a net amount of heat transferred out of a system* such as an air conditioner, a net amount of work must be done on the system $(W_{in} >> W_{out})$.	1	2	3	4	5		1	2	3	4	5
5.	I realize that processes in thermodynamics are mostly processes that operate for long periods of time. Hence we need to consider properties that are steady over that long period during which devices operate. So, we will always consider steady-state flow, where properties remain constant over a long period of time. The most important consequence for the situation is no change in properties within the system's boundary. Hence, the total energy, the	1	2	3	4	5		1	2	3	4	5

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	mass and total volume MUST remain constant throughout the process. Then, $m_{in} = m_{out}$, since $Dm_{sys} = 0$ (kg) OR $\dot{m}_{in} = \dot{m}_{out}$ (kg/s) and $D\dot{E}_{sys} = 0$, (kW). The mass flow rate can be written in terms of the mass velocity, the perpendicular surface area and the specific volume of the mass. An expression for this is $\left(\frac{\vec{v}A}{u}\right)_{in} = \left(\frac{\vec{v}A}{u}\right)_{out}$, (kg/s)											
6.	I can now write the energy balance for steady flow CV as $\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} + \sum(\dot{m}q)_{in} - \sum(\dot{m}q)_{out} = 0$, (kW). Rearranging the expression, I can write the energy balance for steady flow CV as $\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \sum(\dot{m}q)_{out} - \sum(\dot{m}q)_{in}$, (kW) or in units of kJ/kg, it is $q_{in} - q_{out} + w_{in} - w_{out} = \sum(q)_{out} - \sum(q)_{in}$. Note that the right side of this expression represents the energy of the moving mass. If the mass is not flowing, then the right side is zero and the expression is similar to the stationary closed system discussed before. The summation in the expression is needed to safeguard you against making assumptions that each inlet or outlet carries the same energy. Each inlet has a unique energy that must be distinguished from other inlets or outlets. If there are 2 inlets and one outlet and if state 1, state 2 and state 3 are used to label the inlets and outlet respectively, then the energy balance is $\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}_3 q_3 - \dot{m}_1 q_1 - \dot{m}_2 q_2$ and the mass balance is $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$	1	2	3	4	5		1	2	3	4	5
7.	For a single stream (one inlet and one outlet only) steady flow CV, the mass balance is $\dot{m}_1 = \dot{m}_2$ and the energy balance is $\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = (\dot{m}q)_2 - (\dot{m}q)_1 = \dot{m}(q_2 - q_1)$. In terms of the mass flow total energy, it is $\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(q_2 - q_1) = \dot{m}(h_2 - h_1 + ke_2 - ke_1 + pe_2 - pe_1) = \dot{m}(Dh + Dke + Dpe)$ or in units of kJ/kg, it is $q_{in} - q_{out} + w_{in} - w_{out} = q_{out} - q_{in} = Dh + Dke + Dpe$ where $q = \frac{\dot{Q}}{\dot{m}}$, & $w = \frac{\dot{W}}{\dot{m}}$ Note that the kinetic and potential energy changes are $Dke = \frac{\vec{v}_2^{\,2} - \vec{v}_1^{\,2}}{2000}$, (kJ/kg) and $Dpe = \frac{gy}{1000}$, (kJ/kg), respectively where y is the vertical distance.	1	2	3	4	5		1	2	3	4	5

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8.	I am aware that processes always occur in its natural direction and not the reverse. A cup of hot coffee naturally will cool to room temperature when placed on a table. An object at a certain height will naturally fall down to the ground when it is released. An object moving at a certain speed will naturally slow down as time goes by due to frictional forces acting on it. In all the examples above, processes will occur in its natural direction as dictated by nature. In addition, each example mentioned above obeys the energy conservation. When the hot coffee cools down to room temperature, its thermal energy is lost to the room $\left(0 - q_{out} + 0 = Du_{coffee}\right)$. The amount of energy lost for each unit mass is the amount gain by the room $\left(q_{in} - 0 + 0 = Du_{room}\right)$. For the case of the falling object, the potential energy lost is transformed $\left(0 - 0 + 0 = 0 + Dke + Dpe\right)$ into kinetic energy and when the object eventually hits the ground, all of the kinetic energy will be converted into thermal energy and sound. The total energy before the fall and after the fall remains the same. Hence, all processes that occur in real life must follow its natural direction and must satisfy the energy conservation.	1	2	3	4	5		1	2	3	4	5
9.	I realize that placing a direction of a process is one statement of the Second Law of Thermodynamics. In other words the second law states that thermodynamics processes proceed in its natural direction. Specifically, thermal energy (heat) flows naturally from a high temperature medium to a low temperature medium. Another statement of the second law asserts that energy has quality. High quality here means that more of the thermal energy can be converted into work. As an example, a system at a temperature of 1000K and with an energy of 1000 kJ has a higher quality that a system that has the same amount of energy but at a temperature of 300K. The system at 1000K can produce more work than the system at 300K even though both have an energy of 1000 kJ.	1	2	3	4	5		1	2	3	4	5
10.	I am aware that a heat engine is required to convert heat into work done. In fact, even with the use of the heat engine, not all the heat can be totally converted in to work when dealing with heat engines that operate in a cycle. Some of the heat that the engine receives must be rejected to a sink in order to return the system in the heat engine back to its original state.	1	2	3	4	5		1	2	3	4	5
11.	I realize that heat engines are characterized by the following four characteristics: (i) Receive heat from a high temperature reservoir (source). (ii) Convert part of that heat into work. (iii) Reject the remaining (excess) heat into a low temperature reservoir (sink). (iv) Operate in a cycle.	1	2	3	4	5		1	2	3	4	5
12.	I can draw an energy-flow diagram to indicate the operation of a steam power plant and able to include the reservoirs and to label all the energy exchanges, q_{in}, w_{out}, q_{out}, and w_{in}. At this point I am already familiar with the expression, $q = q_{net,in} = q_{in} - q_{out}$ and the expression, $w = w_{net,out} = w_{out} - w_{in}$.	1	2	3	4	5		1	2	3	4	5
13.	I am confident that I can write the energy balance for this power plant. Since this is a stationary closed system operating in a cycle, the energy change of the system is zero. Hence the right side of the energy balance is zero.	1	2	3	4	5		1	2	3	4	5

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	Then the energy balance is $q_{in} - q_{out} + w_{in} - w_{out} = 0$. It can be rearranged to be $q_{in} - q_{out} = w_{out} - w_{in}$ or simply written as $q_{net,in} = w_{net,out} \;\; or \;\; q = w$. I am very comfortable to write this energy balance in units of both kilojoule and kilowatt: $Q_{net,in} = W_{net,out} \;\; or \;\; Q = W$ in kJ and $\dot{Q}_{net,in} = \dot{W}_{net,out} \;\; or \;\; \dot{Q} = \dot{W}$ in kW.												
14.	I know that the purpose or the desired output of a power plant is to produce work and the required input is the heat supplied into the boiler. Hence the performance of this power plant or often called as the power plant's thermal efficiency is $Efficiency = \frac{Desired\ \ Output}{Required\ \ Input}$ or written as $h_{th} = \frac{w_{out} - w_{in}}{q_{in}} = \frac{q_{in} - q_{out}}{q_{in}} = \frac{q_{in}}{q_{in}} - \frac{q_{out}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$. Of course I can write, the expressions in different ways: $h_{th} = 1 - \frac{Q_{out}}{Q_{in}}$ and $h_{th} = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}}$. Since the thermal efficiency (a unitless quantity) depends on the ratio of the excess heat with respect to the supplied heat, the thermal efficiency is always smaller that unity and usually expressed in terms of percentage. Hence the thermal efficiency is always less than 100%. The reason is quite obvious. Since a cyclic device need to return to its initial state to restart the cycle, whatever remaining heat has to be rejected to a low temperature reservoir (rejecting to a high temperature reservoir is forbidden because thermal energy cannot flow from a low temperature medium to a high temperature medium). Without rejecting the excess heat, the system cannot return to its initial state and the device cannot operate in a cycle.	1	2	3	4	5		1	2	3	4	5
15.	I realize that a cyclic device such as steam power plant operate between a high temperature reservoir and a low temperature reservoir. Hence the heat exchange Q_{in} can be replaced by Q_H and the heat rejected Q_{out} can be replaced by Q_L. Then the thermal efficiency is $h_{th} = 1 - \frac{q_L}{q_H}$ or $h_{th} = 1 - \frac{Q_L}{Q_H}$ or $h_{th} = 1 - \frac{\dot{Q}_L}{\dot{Q}_H}$.	1	2	3	4	5		1	2	3	4	5
16.	I am aware that to make heat flow ***opposite to its natural direction***, I need a device called a refrigerator. The purpose of a refrigerator is to cool a space or to maintain a refrigerated space at a low temperature by removing or reducing thermal energy (heat) from that space. In order to achieve this purpose, external work has to be done on the device.	1	2	3	4	5		1	2	3	4	5
17.	I can write the energy balance for a refrigerator as $q_{in} - q_{out} + w_{in} - w_{out} = 0$ or $q_{out} - q_{in} = w_{in} - w_{out}$. Then the performance of the refrigerator or coefficient of performance can be obtained by recognizing that the desired output is to cool a space by removing heat $q_{in} = q_L$ from the space intended to be cooled (subscript L is used to denote from a cold reservoir and subscript H is used to denote from a hot reservoir). The required input is the external work done,	1	2	3	4	5		1	2	3	4	5

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	$w_{in} = q_{out} - q_{in} = q_H - q_L$. Hence the coefficient of performance is $COP_R = \frac{q_{in}}{w_{in}} = \frac{q_{in}}{q_{out} - q_{in}} = \frac{1}{\frac{q_{out} - q_{in}}{q_{in}}} = \frac{1}{\frac{q_{out}}{q_{in}} - \frac{q_{in}}{q_{in}}} = \frac{1}{\frac{q_{out}}{q_{in}} - 1} = \frac{1}{\frac{q_H}{q_L} - 1}$. The expression can also be written as $COP_R = \frac{1}{\frac{Q_H}{Q_L} - 1}$ or $COP_R = \frac{1}{\frac{\dot{Q}_H}{\dot{Q}_L} - 1}$. Since the amount of heat rejected to the hot surrounding is bigger than the heat removed from the cold surrounding, $q_{out} = q_H = w_{in} + q_L$, than the COP can have numbers larger than unity. The COP can be as high as 40 and hence it is not written in percentage form.											
18.	I know that a heat pump is like a refrigerator but its purpose is to maintain a heated space at a high T. In order to serve its purpose, thermal energy (heat) has to be supplied to the warm space. Hence the desired output is $q_{out} = q_H$ while the required input remains the same since the device still require the use of a compressor. Hence the coefficient of performance is $COP_{HP} = \frac{q_{out}}{w_{in}} = \frac{q_{out}}{q_{out} - q_{in}} = \frac{1}{\frac{q_{out} - q_{in}}{q_{out}}} = \frac{1}{\frac{q_{out}}{q_{out}} - \frac{q_{in}}{q_{out}}} = \frac{1}{1 - \frac{q_{in}}{q_{out}}} = \frac{1}{1 - \frac{q_L}{q_H}}$. The expression can also be written as $COP_{HP} = \frac{1}{1 - \frac{Q_L}{Q_H}}$ or $COP_{HP} = \frac{1}{1 - \frac{\dot{Q}_L}{\dot{Q}_H}}$. Again the COP is bigger than 1, hence it is not written in percentage form. Note that an air-conditioner when reversed will operate as a heat pump. Reversing the air-conditioner automatically reverses the space. Hence the thermal energy from the surrounding is removed and rejected into the cold room, hence maintaining the room at a high temperature.	1	2	3	4	5		1	2	3	4	5
19.	I realize that reversible means that a process when done along the same path forward and backward will not leave any traces on both the system and the surrounding. In other words the systems' properties must be returned to its original state after the forward and reversed process. Bringing the system back to its original state after the reversed process is called the internally reversible process. In addition, the surrounding's original state must also be returned upon completion of the reversed cycle. If heat was drawn from the surrounding during the forward process, then the surrounding must receive the same amount of heat during the reversed process. If work was done **BY** the	1	2	3	4	5		1	2	3	4	5

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	surrounding during the forward process then the same amount of work must be done **ON** the surrounding during the reversed process. Returning the surrounding to its original state means that the process is externally reversible. Total reversibility or simply referred to as reversible process means that the process must be internally and externally reversible. Whenever heat is drawn during the forward process and work is returned to the surrounding during the reversed process, then the process is rendered irreversible. Processes in real life are ALL IRREVERSIBLE. Reversible processes are ideal processes, dream processes, a model, which we set in order to have a maximum target whenever we deal with real engineering devices. So, don't get carried away. We only need the model so that we can make comparison as to how efficient our machines are with respect to our dream machines. In addition, it is much easier to perform numerical calculations with ideal devices; hence it is possible to set the maximum achievable efficiency for our real everyday machine.											
20.	I know that irreversibilities are caused by three major factors: (i) Frictional forces that exist between two moving surfaces. The energy dissipated due to friction is usually lost in the form of heat. Hence the surrounding usually end up having more internal energy at the end of the reversed cycle, $DU_{surr} \neq 0$, due to receiving more heat than was drawn during the forward process. (ii) Non-quasi equilibrium expansion and compression (at every state during the expansion or compression, the path followed does not contain equilibrium states). This usually happens because processes are done too fast resulting in the system not having sufficient time to achieve equilibrium. As a result the surrounding cannot return to its original state after the reversed cycle (the amount of heat drawn is not equal to the amount of heat received, $\left(Q_{out} - Q_{in}\right)_{surr} \neq 0$, and work done by the surrounding is not equal to the amount of work done on the surrounding, $\left(W_{in} - W_{out}\right)_{surr} \neq 0$). (iii) Non-isothermal heat transfer (heat transfer through a finite temperature difference). Ideally, when heat is drawn or returned to the surrounding, it must be done very slowly in order for the system and surrounding to be in thermal equilibrium (isothermal) during the process of heat transfer. Unfortunately, this is not possible because it may take a very long time (could be years) to complete a cycle. Real expansion and compression happens very fast, hence the process is non-isothermal. Furthermore, recall that heat transfer at the system's boundary can only happen if there is a temperature difference between the system and the surrounding. Hence, an isothermal heat transfer is only a dream process.	1	2	3	4	5		1	2	3	4	5
21.	I realize that the most efficient engine, which has the highest engine's efficiency, is an engine that employs reversible cycles. It means that every process in the cycle for a power plant must be reversible. This cycle is called the Carnot cycle and the efficiency is called the Carnot efficiency, $h = h_{rev}$. Recalling that in power plant, the purpose is to produce work by absorbing heat from a high temperature reservoir (source). (i) The first process in the cycle is a reversible isothermal expansion. Heat is transferred to the system causing the system to expand and hence do work on the surrounding. Then employing the first law for this process, I	1	2	3	4	5		1	2	3	4	5

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	can write, $Q_{in} - 0 + 0 - W_{out} = 0$. (ii) The second process in the cycle is the reversible adiabatic expansion. Since the system is perfectly insulated, and there is no heat transfer through the system's boundaries, the expansion process is a spontaneous expansion. The internal energy of the system is used for the expansion resulting in the drop of the internal energy at the end of the expansion as indicated by the drop in temperature and the pressure of the system. The energy balance can be written as $0 - 0 + 0 - W_{out} = U_2 - U_1 < 0$. (iii) The third process is to reject the excess heat into a low-temperature surrounding (sink). Again, this is an isothermal (hence reversible) process or isothermal compression. The energy balance is $0 - Q_{out} + W_{in} - 0 = 0$. Clearly, all the work done on the system is rejected isothermally to the low-temperature sink. (iv) The last process in the Carnot cycle is the reversible adiabatic compression. Further compression of the system while the system is insulated from the surrounding is done to return the system to its original state. The energy balance is $0 - 0 + W_{in} - 0 = U_2 - U_1 > 0$. Since there is no way for heat to be rejected, then all the work done on the system will be stored as internal energy of the system. This is shown by the increase in the system's internal energy as physically indicated by the increase in the system's temperature and pressure.											
22.	I am able to sketch a P-ν diagram for the Carnot cycle and label the energy exchanges. In addition, I can also write the energy balance for the cycle by treating the cycle as a stationary closed-system undergoing a cycle. The energy balance is $Q_{in} - Q_{out} + W_{in} - W_{out} = 0$. The energy balance can be simplified as $W_{out} - W_{in} = Q_{in} - Q_{out}$ or in unit mass form, $w_{out} - w_{in} = q_{in} - q_{out}$ or in rate form, $\dot{W}_{net,out} = \dot{W}_{out} - \dot{W}_{in} = \dot{Q}_{in} - \dot{Q}_{out}$. I also realize that the area underneath the P-ν diagram represents the specific work done by the power plant.	1	2	3	4	5		1	2	3	4	5
23.	I realize that I can determine the maximum efficiency of a real engine by determining the efficiency of the Carnot engine since this engine employs reversible processes in its cycle. In order to do that I must first be able to state the Carnot's Principle. The principle states that for heat engines operating between the *same hot and cold reservoirs*, the efficiencies of the engines are equal for all reversible engines, $h_{rev_1} = h_{rev_2} = h_{rev_3}$ but irreversible engines have smaller efficiencies than the reversible engines, $h_{irrev} < h_{rev}$ regardless of the working fluid used in the engines. The implication of this principle is that all real devices will always have efficiencies smaller that the Carnot (reversible) engines. Another more important implication of the Carnot Principle is the definition of absolute temperature that is measured in Kelvin. Of significance is the fact that the ratio of heat exchanges can be replaced by the ratios of	1	2	3	4	5		1	2	3	4	5

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	absolute temperatures for Carnot engines and can be written as, $\left(\frac{Q_L}{Q_H}\right)_{rev}=\frac{T_L(K)}{T_H(K)}$, or in the unit-mass basis, it is, $\left(\frac{q_L}{q_H}\right)_{rev}=\frac{T_L(K)}{T_H(K)}$, and in the rate-form it is, $\left(\frac{\dot{Q}_L}{\dot{Q}_H}\right)_{rev}=\frac{T_L(K)}{T_H(K)}$.											
24.	I realize that the purpose of a steam power plant is to produce work from the heat absorbed and I am confident that the efficiencies for steam power plants can be written as, $h_{rev}=\left(\frac{w_{net,out}}{q_{in}}\right)_{rev}=\left(\frac{q_{in}-q_{out}}{q_{in}}\right)_{rev}=1-\left(\frac{q_{out}}{q_{in}}\right)_{rev}=1-\left(\frac{q_L}{q_H}\right)_{rev}=1-\frac{T_L(K)}{T_H(K)}$ and for real steam power plants, it is $h_{irrev}=1-\frac{q_L}{q_H}$. Hence for Carnot engines, I can just determine the efficiencies if I know the reservoirs absolute temperatures, T_L and T_H.	1	2	3	4	5		1	2	3	4	5
25.	I realize that the purpose of a refrigerator is to cool a space or maintain a space at a low temperature by removing heat from the space. Then I can confidently write the efficiencies for a Carnot refrigerator as $COP_{R,rev}=\left(\frac{q_{in}}{w_{in}}\right)_{rev}=\left(\frac{q_{in}}{q_{out}-q_{in}}\right)_{rev}=\frac{1}{\left(\frac{q_{out}}{q_{in}}\right)_{rev}-1}=\frac{1}{\left(\frac{q_H}{q_L}\right)_{rev}-1}=\frac{1}{\frac{T_H(K)}{T_L(K)}-1}$. The efficiency of a real (irreversible) refrigerator is $COP_{R,irrev}=\frac{1}{\frac{q_H}{q_L}-1}$. I also realize that the area under a P-ν diagram represents the specific work done on the system.	1	2	3	4	5		1	2	3	4	5
26.	I realize that the purpose of a heat pump is to maintain a space at a high temperature by supplying heat to the space. Then I can confidently write the efficiencies for a Carnot (reversible) heat pump as $COP_{HP,rev}=\left(\frac{q_{out}}{w_{in}}\right)_{rev}=\left(\frac{q_{out}}{q_{out}-q_{in}}\right)_{rev}=\frac{1}{1-\left(\frac{q_{in}}{q_{out}}\right)_{rev}}=\frac{1}{1-\left(\frac{q_L}{q_H}\right)_{rev}}=\frac{1}{1-\left(\frac{T_L(K)}{T_H(K)}\right)_{rev}}$. The efficiency of a real	1	2	3	4	5		1	2	3	4	5

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	(irreversible) heat pump is $COP_{HP,irrev} = \frac{1}{1-\frac{q_L}{q_H}}$.											