

The Big Ideas—Chapter 20

(Serway and Beichner, Physics for Scientists and Engineers, 5th Edition)

<p><i>Section 1</i></p> <p>Heat, like work, refers to a <i>transfer</i> of energy from one system to another. Objects do not “have” heat; they “have” internal energy. The internal energy of an object may be changed via mechanical processes (i.e., those that involve <i>work</i>) or via thermal processes (i.e., those that involve <i>heat</i>.)</p> <p>Note that, although heat is a flow of energy <i>from</i> an object at a higher temperature <i>to</i> an object at a lower temperature that occurs <i>as a result</i> of the temperature difference, temperature itself is not a measure of <i>heat</i>. For instance, we can “warm” something (i.e., increase its temperature) by doing a suitable amount of <i>work</i> on it.</p> <p>An archaic unit of heat—the calorie—created at a time when people thought heat itself <i>was</i> a sort of fluid that objects “contained” is still used today even though we now know that it is simply an alternate unit of energy.</p>	<p style="text-align: center;">1 cal 4.186 J</p>
<p><i>Section 2</i></p> <p>The “heat capacity” of an <i>object</i> is the change in internal energy (not necessarily heat!) per unit change in temperature. By definition it is an <i>extensive</i> quantity—i.e., it depends on the <i>amount</i> of “stuff.” The “specific heat” of a <i>substance</i> is the change in internal energy per unit mass per change in temperature. By definition it is an <i>intensive</i> quantity—i.e., it depends only on the <i>identity</i> of the substance.</p> <p>These two quantities have <i>very</i> unfortunate names!! For instance, the heat capacity of an object has nothing specifically to do with “heat” (it has to do with changes in <i>internal energy</i> which may be the result of heat or work) <i>nor</i> should it be taken to imply that objects have a finite capacity for “heat” (or <i>even</i> for changes in internal energy!)</p> <p>The “heat capacity” of an object is just the sum of the heat capacities of its constituent parts with heat capacity of each part depending on its own mass and the “specific heat” of the substance of which it is composed.</p>	$C = \frac{E_{\text{int}}}{T}$ $c = \frac{E_{\text{int}}}{m T}$ $C = m_1 c_1 + m_2 c_2 + \dots$

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<p><i>Section 2 (cont'd)</i></p> <p>When different objects are in thermal contact with each other but do not exchange energy of any type with their surroundings, they will reach thermal equilibrium while conserving their initial energy. Devices in which such processes can be carried out are called <i>calorimeters</i> and the analysis of these processes is called <i>calorimetry</i>.</p> <p>Calorimetry involves <i>nothing</i> more than the use of conservation of energy along with a knowledge of the connection between temperature and internal energy through quantities like <i>specific heats</i> and <i>latent heats</i> (see the next section.)</p>	
<p><i>Section 3</i></p> <p>Melting and vaporizing are common examples of what are more generally called “changes of phase.” When a substance melts it changes from the solid “phase” to the liquid “phase.” When it vaporizes it changes from the liquid “phase” to the vapor or gas “phase.” During a phase change, the internal energy changes <i>without</i> a corresponding change in temperature. The “latent heat” of a <i>substance</i> is the change in internal energy (again, <i>not necessarily heat!</i>) per unit mass that undergoes the phase change. By definition it is an <i>intensive</i> quantity—i.e., it depends only on the <i>identity</i> of the substance.</p> <p>Calorimetry involving phase changes requires a knowledge of the corresponding latent heats.</p>	$L = \frac{E_{\text{int}}}{m}$
<p><i>Section 4</i></p> <p>In thermodynamics we are concerned with the so-called thermodynamic “state” of the system which is specifically characterized by “state variables”—things like pressure, volume, internal energy, and temperature. The “state” of a system and, therefore, the values of its “state variables” can be altered either mechanically or thermally—that is, by processes that involve either work or heat.</p> <p>Note that many of the quantities used to specify the thermodynamic state of a system can only be sensibly defined for a system that is in “thermal equilibrium.”</p>	

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<p><i>Section 4 (cont'd)</i></p> <p>A “quasistatic process” is one in which the system is always approximately in thermal equilibrium.</p> <p>The state of a given amount of gas can be fully specified by its pressure and volume. Furthermore, the work it does on its surroundings can be determined in terms of how its pressure changes as its volume changes.</p> <p>On a <i>PV</i> diagram, the work done by the gas in any quasistatic process is simply the area under the curve representing the process.</p> <p>Since the internal energy of a gas is a “state variable” the change in the internal energy of a gas depends only on its initial and final “states.” The work done by the gas, however, depends on the details of the <i>process</i> by which the gas changes its state.</p>	$W = PdV$
<p><i>Section 5</i></p> <p>The “first law of thermodynamics” (FLT) says that, in <i>any</i> process, the change in the internal energy of a system is equal to the heat transfer <i>to</i> it minus the work done <i>by</i> it.</p> <p>The FLT is <i>nothing</i> more than the law of conservation of energy in a form that recognizes both mechanical and thermal means of transferring energy from one system to another.</p> <p>Please note that <i>many</i> books use different conventions for the signs for Q and W. It is especially common for texts to define <i>positive</i> work as work done <i>on</i> the system (rather than work done <i>by</i> the system as is the case in this text.) In that case the FLT is written purely with “+” signs.</p> <p>A “cyclic process” is one in which the initial and final states are the same. For a cyclic process, $E_{\text{int}} = 0$ so $Q = W$.</p>	$E_{\text{int}} = Q - W$
<p><i>Section 6</i></p> <p>Several important thermodynamic processes involve holding some specific state variable constant or disallowing work or heat.</p> <p>In an “isobaric” process, the pressure is held (approximately) constant. Since pressure is a state variable such a process is necessarily performed quasistatically. The work is easily calculated.</p>	$W_{\text{isobaric}} = P \Delta V$

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<p>In an “isovolumetric” (or “isochoric”) process, the volume is held (approximately) constant. Note that no work is done in an isovolumetric process and that the FLT, therefore, gives the heat.</p> <p>In an “isothermal” process, the temperature is held (approximately) constant. Since temperature is a state variable such a process is necessarily performed quasistatically. Note that, for an ideal gas, the pressure is inversely proportional to volume and the work is easily calculated.</p> <p>In an “adiabatic” process, $Q = 0$. Because Q is <i>not</i> a state variable, such a process may be performed quasistatically or <i>nonquasistatically</i> as, for instance, in a “free expansion.” The FLT gives the work.</p>	$W_{\text{isovolumetric}} = 0$ $Q_{\text{isovolumetric}} = E_{\text{int}}$ $W_{\text{isothermal/ideal gas}} = nRT \ln(V_f/V_i)$ $W_{\text{adiabatic}} = - E_{\text{int}}$
<p><i>Section 7</i></p> <p>Thermally induced transfers of energy may be accomplished via three mechanisms: Conduction, convection, and radiation.</p> <p>Conduction is the thermally-induced flow of energy <i>through</i> a material via “collisions” at the atomic level. The rate at which energy flows depends on the “temperature gradient” across the material, the area perpendicular to the heat flow, and the “thermal conductivity” of the material (another “intensive” quantity.)</p> <p>It is convenient to characterize the “thermal insulation” property of a compound “slabs” in terms of its “R-value.” The rate of energy flow through such a slab depends only on the area and the temperature difference.</p> <p>Convection is the flow of a warm fluid into a region of cold fluid. Convection is a thermomechanical process that can be the <i>natural</i> result of gravitationally induced pressure gradients or the <i>forced</i> result of agents like fans.</p> <p>Radiation is the flow of energy via electromagnetic waves. All objects emit thermal radiation at a rate that is proportional to their area and the <i>fourth power</i> of their absolute temperature as given by Stefan’s law. Because of the extreme temperature dependence, warmer objects tend to radiate <i>far</i> more energy than colder objects.</p>	$P_{\text{cond}} = kA \left[\frac{dT}{dx} \right]$ $R = \sum_i R_i$ $P_{\text{cond}} = \frac{A}{R} T$ $P_{\text{rad}} = e AT^4$