PURDUE UNIVERSITY — DEPARTMENT OF PHYSICS

Physics 22000
General Physics
Lecture 26 – Heat

Fall 2016 Semester
Prof. Matthew Jones

Final Exam

Examination Schedule
Fall 2016 (PWL)

Filter

Term: Fall 2016 (PWL) · Exams: Final · Subject: PHYS · Apply

Fall 2016 (PWL) final examinations (PHYS)

| Subject	Course	CRN	Section	Date	Time	Room
PHYS	17200			Wed 12/14	1:00p - 3:00p	LAMB F101
PHYS	17200H	26979	26979-H01	Mon 12/12	8:00a - 10:00a	PHYS 114
PHYS	21400	26984	26984-001	Tue 12/13	10:30a - 12:30p	PHYS 114
PHYS	21500	26987	26987-001	Fri 12/16	1:00p - 3:00p	PHYS 112
PHYS	21800	16840	16840-014	Mon 12/12	7:00p - 9:00p	HIKS B848
PHYS	21800	26997	26997-001	Fri 12/16	1:00p - 3:00p	PHYS 114
PHYS	21900	27009	27009-001	Wed 12/14	1:00p - 3:00p	PHYS 112
PHYS	22000			Fri 12/16	1:00p - 3:00p	LAMB F101
PHYS	22100			Wed 12/14	1:00p - 3:00p	LILY 1105
PHYS	23300	67161	67161-001	Fri 12/16	8:00a - 10:00a	EE 129
PHYS	23400	10833	10833-001	Fri 12/16	8:00a - 10:00a	PHYS 111

Final Exam

- Same format as previous exams
- You can bring one page of your notes
- Equation sheet will be provided with the exam
- Bring your ID, a calculator and a pencil
- Mainly covers material since last exam with some overlap (roughly lectures 18-26)

Free Study Sessions!

SUPPLEMENTAL INSTRUCTION

Rachel Hoagburg

Come to SI for more help in **PHYS 220**

| Tuesday and Thursday | 7:30-8:30PM Shreve C113 |

Office Hour
Tuesday 1:30-2:30 4th floor of Krach

For other SI-linked courses and schedules, visit purdue.edu/si or purdue.edu/boilerguide

Work Done on a Piston

- If there is a pressure difference between the inside and outside of the cylinder, then it will exert a force.
- If the piston moves, then work will be done.
- P, V and T will always satisfy the ideal gas law.
- We can change T by exchanging heat with the environment.
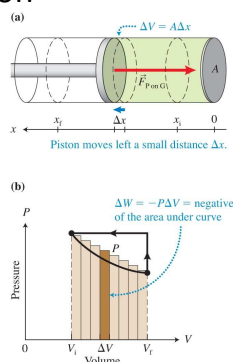
Work depends on the process between the initial and final states

- In Figure 12.4a, to go from the initial state to the final state, the gas first has a constant volume and increasing pressure, and then has a constant pressure and decreasing volume.
- In Figure 12.4b, the gas first has a constant pressure/volume decrease, and then has a constant volume/pressure increase to reach the same final state.
- The work done for each process is different.
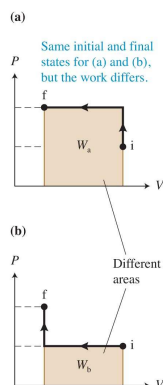
The first law of thermodynamics

First law of thermodynamics
Consider a process involving a system of interest. The system's internal energy change $(U_f - U_i) = \Delta U_{\text{System}}$ is equal to the amount of work W done on the system plus the amount of energy Q transferred to the system through the process of heating:

$$W_{\text{Environment on System}} +$$
$$Q_{\text{Environment to System}} = \Delta U_{\text{System}}$$
$$(12.4a)$$

Analyzing gas processes

Table 12.6 Application of the first law to gas processes. In each process, the gas starts at position 1 (the initial state) on the *P*-versus-*V* graph and moves to position 2 (the final state).

Process	Graph	Particle-level explanation	Explanation and bar chart using the first law of thermodynamics
(a) *Isothermal process (constant temperature)* The gas is in a non-insulated container with a piston, all submerged in a large bath of water at constant temperature, which is the same as the temperature of the gas. Someone pulls the piston out very slowly.	P, 1, $T = \text{const}$, 2, V	As the piston is pulled out, the gas molecules collide elastically with the piston and rebound at a slower speed than before the collision, which causes a temperature decrease. But the container is in contact with the water bath, which provides heating so the gas remains at constant temperature.	■ As the temperature of the gas stays constant, $\Delta U_{\text{int}} = 0$. ■ The external work done on the gas is negative ($W < 0$). ■ Transfer of energy through heating ($Q > 0$) is needed to make the internal energy change zero. ■ $-|W| + Q = 0$

Analyzing gas processes

Table 12.6 Application of the first law to gas processes. In each process, the gas starts at position 1 (the initial state) on the *P*-versus-*V* graph and moves to position 2 (the final state). *(Continued)*

Process	Graph	Particle-level explanation	Explanation and bar chart using the first law of thermodynamics
(b) *Isochoric process (constant volume)* The gas is in a noninsulated container with a fixed piston. The container is placed in a bath of higher temperature. The temperature of the gas increases.	P, 2, 1, V	As the gas warms, its molecules move faster and faster, colliding with the walls of the container more often and more violently. The gas pressure increases.	■ Because the volume is constant, there is no work done on the gas ($W = 0$). ■ Energy is transferred to the gas through heating ($Q > 0$). ■ Transfer of energy through heating leads to an increase in the thermal energy of the gas ($\Delta U_{\text{int}} > 0$). ■ $0 + Q = +\Delta U_{\text{int}}$

Analyzing gas processes

Table 12.6 Application of the first law to gas processes. In each process, the gas starts at position 1 (the initial state) on the *P*-versus-*V* graph and moves to position 2 (the final state). *(Continued)*

Process	Graph	Particle-level explanation	Explanation and bar chart using the first law of thermodynamics
(c) *Isobaric process (constant pressure)* Gas is in a noninsulated container that has a piston that can move freely up (or down), keeping the gas at constant pressure. The container is placed in a bath at higher temperature, causing the gas to expand at constant pressure.		The hot temperature bath warms the gas by heating. But the gas warms less because the piston moves outward, slowing the particles that hit it and also causing negative work to be done by the environment on the gas.	■ The environment does negative work on the gas ($W < 0$). ■ Energy is transferred through heating ($Q > 0$) and is greater than the negative work. ■ The thermal energy of the gas increases ($\Delta U_{int} > 0$). ■ $-\lvert W\rvert + Q = +\Delta U_{int}$

Analyzing gas processes

Table 12.6 Application of the first law to gas processes. In each process, the gas starts at position 1 (the initial state) on the *P*-versus-*V* graph and moves to position 2 (the final state). *(Continued)*

Process	Graph	Particle-level explanation	Explanation and bar chart using the first law of thermodynamics
(d) *Adiabatic process (no energy transferred through heating)* The gas is in a thermally insulated container or is compressed very quickly.		As the gas is being compressed, the molecules collide with a piston moving inward; the speed of the particles reflected off the incoming piston is greater than before, and the gas's temperature increases.	■ The environment does positive work on the gas ($W > 0$). ■ Since the process happens very quickly or the gas is in an insulated container, we assume that there is no transfer of energy through heating ($Q = 0$). ■ The internal thermal energy of the gas increases ($\Delta U_{int} > 0$). ■ $W + 0 = +\Delta U_{int}$

Specific heat

Specific heat c is the physical quantity equal to the amount of energy that needs to be added to 1 kg of a substance to increase its temperature by 1 °C. The symbol for specific heat is c and the units are $\dfrac{\text{J}}{\text{kg} \cdot {}^{\circ}\text{C}}$. This energy is added through heating or work or both.

$$\Delta U = cm\Delta T$$

Specific heats of various solids and liquids

Table 12.5 Specific heats (c) of various solid and liquid substances.

Solid Substances	c (J/kg • °C)	Liquid Substances	c (J/kg • °C)
Iron, steel	450	Water	4180
Copper	390	Methanol	2510
Aluminum	900	Ethanol	2430
Silica glass	840	Benzene	1730
Sodium chloride	860	Ethylene glycol	2420
Lead	130		
Ice	2090		
Wood	~1700		
Sand	~800		
Brick	~800		
Concrete	~900		
Human body	~3500		

Changing state

- The transformation of ice into water is a phase change—a process during which a substance changes from one state to another. Let's consider an experiment involving the heating of water that starts as very cold solid ice.

A Warming ice
B Melting ice
C Warming water
D Boiling water
E Warming steam
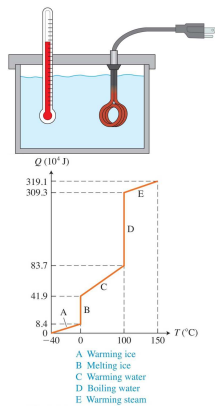
Melting and freezing

- At 0 °C, the phase change graph becomes vertical. The ice starts to melt but the thermometer reading does not change, even though energy is being added to the system.

A Warming ice
B Melting ice
C Warming water
D Boiling water
E Warming steam
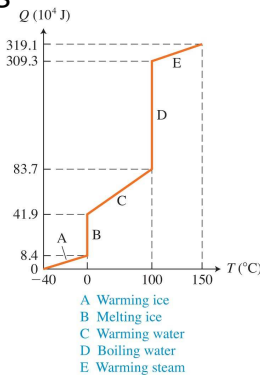
Melting and freezing

- When we transfer energy to the solid material at the melting temperature, all of this energy goes into changing the potential energy of particle interactions, not the kinetic energy—thus the temperature does not change.

(a) H$_2$O solid

(b) H$_2$O liquid

Energy to melt or freeze: Latent heat of fusion

Energy to melt or freeze The energy in joules needed to melt a mass m of a solid at its melting temperature, or the energy released when a mass m of the liquid freezes at that same temperature, is
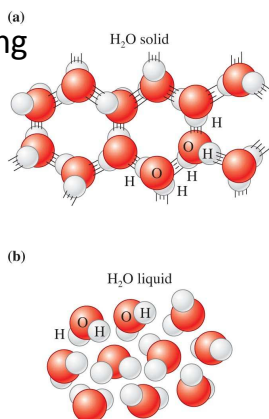
$$\Delta U_{int} = \pm mL_f \qquad (12.6)$$

L_f is the **heat of fusion** of the substance (see Table 12.7). The plus sign is used when the substance melts and the minus sign when it freezes.

TIP The term heat of fusion is confusing, as the word *heat* is often associated with warming, that is, temperature change. In the case of melting or freezing, there is no temperature change. However, there is still change in internal energy—the potential energy of interactions of the particles in the system.

Boiling and condensation

- The temperature of the water remains at the boiling temperature until all of the liquid water boils into vapor. Energy has been added to the water, but its temperature does not change.

$Q\ (10^4\ \text{J})$

319.1
309.3
E

D

83.7

41.9
C

A B
8.4
0
−40   0   100   150 $T\ (°C)$

A Warming ice
B Melting ice
C Warming water
D Boiling water
E Warming steam

Boiling and condensation

- For a molecule to leave the surface of a liquid, it must have enough kinetic energy to break away from the neighboring molecules, which are exerting attractive forces on it. The energy transferred to the liquid leads to a change in the potential energy component of the internal energy.

(a)

A water molecule at the surface of the water is prevented from leaving the water by its attraction to neighboring molecules.

(b)

H O H Fast   Slow O H
                        H

A fast-moving water molecule can escape from a liquid when it hits the surface. A slow-moving one cannot escape.
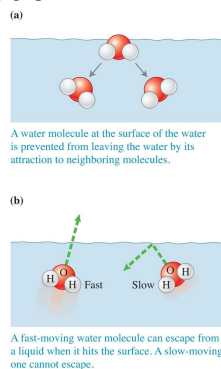
Energy to boil or condense: Heat of vaporization

Energy to boil or condense The energy in joules needed to vaporize a mass m of a liquid at its boiling temperature, or the energy released when a mass m of a gas condenses at that same temperature is
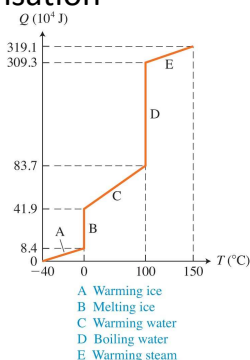
$$\Delta U_{\text{int}} = \pm m L_v \qquad (12.7)$$

L_v is the **heat of vaporization** of the substance (see Table 12.7). The plus sign is used when the substance vaporizes and the minus sign when it condenses.

Heats of fusion and vaporization

Table 12.7 Heats of fusion and vaporization.

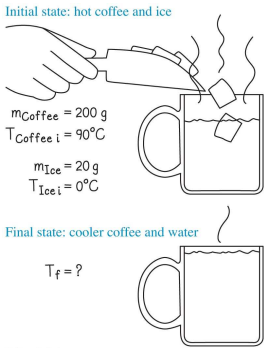| Substance	Melting temperature (°C)	L_f, Heat of fusion at the melting temperature (J/kg)	Boiling temperature (°C)	L_v, Heat of vaporization at the boiling temperature (J/kg)
Water	0	3.35×10^5	100	2.256×10^6
Ethanol	−114	1.01×10^5	78	0.837×10^6
Hydrogen (H_2)	−259	0.586×10^5	−253	0.446×10^6
Oxygen (O_2)	−218	0.138×10^5	−183	0.213×10^6
Nitrogen (N_2)	−210	0.257×10^5	−196	0.199×10^6
Aluminum	660	3.999×10^5	2520	10.9×10^6
Copper	1085	2.035×10^5	2562	4.73×10^6
Iron	1538	2.473×10^5	2861	6.09×10^6

Things to notice about melting and boiling

- The values for the heats of fusion and vaporization are much larger than the specific heat. Much more energy is needed to change the state of a substance than to change its temperature.
- The values for heat of vaporization are significantly larger than the values for heat of fusion. More energy is required to boil the same mass of the same substance than to melt it.

Example 12.8

- You add 10 g of ice at temperature 0 °C to 200 g of coffee at 90 °C. Once the ice and coffee reach equilibrium, what is their temperature? Indicate any assumptions you made.

Initial state: hot coffee and ice

$m_{Coffee} = 200$ g
$T_{Coffee\ i} = 90°C$

$m_{Ice} = 20$ g
$T_{Ice\ i} = 0°C$

Final state: cooler coffee and water

$T_f = ?$

Heating mechanisms

- How can we reduce energy losses from our homes during the winter?
- Why is the "dry heat" in Arizona less uncomfortable than a hot, humid day in Mississippi?
- Why should we be concerned about climate change?
- These questions are related to energy transfer mechanisms and, in particular, to the rate at which these transfers occur.

Conduction

- The process by which thermal energy is transferred through physical contact is called conductive heating or cooling.
- A quantity called thermal conductivity K characterizes the rate at which a particular material transfers thermal energy.
  - You want to use a material with low thermal conductivity to make a cup for holding hot beverages.

Conductive heating/cooling

Conductive heating/cooling The rate of conductive heating $H_{\text{Conduction}}$ from the hot side of a material to the cool side is proportional to the temperature difference between the two sides ($T_{\text{Hot}} - T_{\text{Cool}}$), the thermal conductivity K of the material separating the sides, and the cross-sectional area A across which the thermal energy flows. The rate is inversely proportional to the distance l that the thermal energy travels.

$$H_{\text{Conduction}} = \frac{Q_{\text{Hot to Cool}}}{\Delta t} = \frac{KA(T_{\text{Hot}} - T_{\text{Cool}})}{l} \qquad (12.8)$$

Thermal conductivity of materials (at 25 °C)

Table 12.8 Thermal conductivity of materials (at 25 °C).

Material	κ (W/m · °C)
Metals	
Aluminum	250
Brass	109
Copper	400
Stainless steel	16
Other solids	
Soil	0.6–4
Brick	1.31
Concrete, stone	1.7
Attic insulation	0.04
Glass, window	0.9
Ice (at 0 °C)	2.18
Styrofoam	0.03
Wood	0.04–0.14
Fat	0.2
Muscle	0.4
Bone	0.4
Other materials	
Air	0.024
Water	0.58

Evaporative heating/cooling

Evaporative heating/cooling Evaporative heating occurs when a gas condenses on a surface. Evaporative cooling occurs when a liquid evaporates from a surface. The evaporative energy transfer rate $H_{\text{Evaporation}}$ is proportional to the rate at which liquid mass evaporates or condenses $\Delta m/\Delta t$ on the surface and to the heat of vaporization L_v of the liquid at the temperature of the liquid:

$$H_{\text{Evaporation}} = \pm\left(\frac{\Delta m}{\Delta t}\right)L_v \qquad (12.9)$$

Forced convective heating/cooling

1. Cool water travels from radiator to engine (forced convection).

2. Water passes through hot engine cooling the engine and warming water (conduction).

Radiator — Engine

Air

4. Air passes through radiator causing hot water to cool (convection).

3. Hot water travels from engine to radiator (forced convection).

Radiative heating/cooling

Radiative heating/cooling All objects, hot and cool, emit different forms of radiation that can travel through a vacuum. The hotter the object, the greater the rate of radiation emission. Objects in the path of this radiation may absorb it, gaining energy.