Name: _____

PHYS 1110-02 Exam 4

You may use an 8.5"×11" note sheet written on both sides and a calculator. Please write your answers in the boxes provided. Show your work outside the boxes. Include the units with your answers.

If you need to change the answer you wrote in a box, erase it completely and write your intended answer. This is easiest if you write in pencil. You have 120 minutes. To answer a question asking you to select from a list of provided options, fill the circle or square of your choice. Avoid out-of-bounds marks such as checks or x's. To remove an erroneous choice, cleanly erase the previous mark. Again, this is easiest if you write in pencil.

Some physical constants you might want to know are:

Universal gravitation constant	$G = 6.674 \times 10^{-11} \frac{\mathrm{N \cdot m^2}}{\mathrm{kg^2}}$
Boltzmann constant	$k = 1.381 \times 10^{-23}$
Avogadro's number	$N_A = 6.022 \times 10^{23}/\mathrm{mol}$
Gas constant	$R = 8.314 \frac{\mathrm{J}}{\mathrm{mol \cdot K}}$
Specific heat capacity of water	$4.184 \frac{\mathrm{kJ}}{\mathrm{kg \cdot K}}$

1. (4 points) The current time is a golden age in astronomy for detecting planets that orbit stars other than our Sun. Suppose a student examining the light curve for a star known to have a mass of 5.00×10^{29} kg finds a decrease in the star's output every 2.00×10^{6} seconds (23.1 days). This is interpreted as an orbiting planet blocking some of the light from the star as it orbits. What is the average orbital distance of the planet from the star? (Don't forget to report the units!)

2. A planet of mass m orbits a star of mass M at a distance r.
   A. (1 point) What is the formula for the orbital kinetic energy K of the planet? Express in terms of the quantities M, m, and r.

   B. (1 point) What is the formula for the gravitational potential energy U_g of the planet in its orbit? Express in terms of the quantities M, m, and r.

C. (1 point) How much kinetic energy E would the planet need to escape from (no longer be gravitationally bound to) the star? (Tell me the total kinetic energy, not the additional energy it would need from its orbit.) Express in terms of the quantities M, m, and r.

D. (1 point) What is the ratio K/U_g?

E. (1 point) What is the ratio K/E?

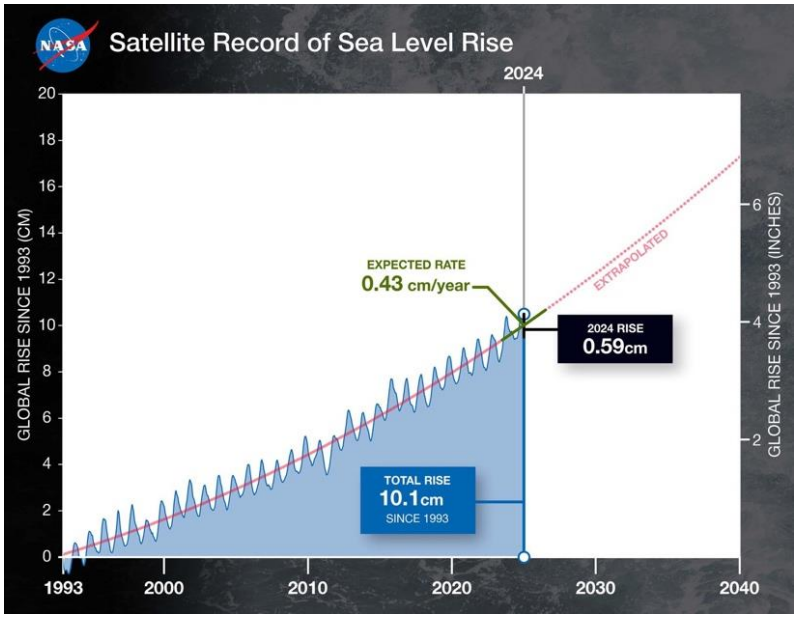
F. (1 point) What is the ratio U_g/E?

3. A 0.700-kilogram sample of a proprietary material used for heat packs is warmed from 20°C to 50°C, while heat input and temperature are recorded. At 20°C, the sample is a soft solid. Between 20.0°C and 45.0°C, it absorbs 45.3 kJ of heat. At 45°C, the sample melts, requiring an input of 73.5 kJ of heat to fully melt. Once the sample is fully liquid, it absorbs 9.1 kJ of heat to reach its final temperature of 50.0°C.

   A. (5 points) What is the specific heat capacity of the solid material? (Don't forget to report the units!)

   B. (5 points) What is the material's latent heat of melting? (Don't forget to report the units!)

4. (10 points) Worldwide sea level has been rising since the last ice age, but its rate of rising has increased in recent years. The diagram below shows the global sea level change since 1993, based on NASA satellite observations. Some of this rise is attributed to melting of ice on land, and the rest to thermal expansion of the top layer of the ocean.



Suppose that half the rise, or 5.00 centimeters, is because of thermal expansion of the top 500 meters of ocean water. By what amount would the temperature of the water in this layer need to increase to produce this increase in thickness? Assume that the area of the layer does not change as it expands (not true, but pretty close). The coefficient of volume expansion of water at surface temperature[1] is $\beta = 1.51 \times 10^{-4}/°\text{C}$.

[1] The coefficient of thermal expansion of liquid water varies with temperature, but we can treat it as constant over a small temperature change.

5. A dark-colored balloon outside in the Sun on a bright summer day heats up at a constant pressure of 95.0 kilopascals (1 kilopascal = 1000 pascals). Its initial volume is 1.700 liters; it absorbs 27.1 joules of heat to expand to a volume of 1.814 liters.

   A. (5 points) How much work does the air inside the balloon do as it expands?

   B. (5 points) What is the change in internal energy of the air inside the balloon?

6. (5 points) When a gas confined to a small volume is allowed to expand into an empty space with larger volume, it always spreads out to fill the larger volume. Gas in a large volume never spontaneously collapses to a smaller volume.[2] Why are the two directions of this process so different? Select the best explanation.

   ○ a. All systems tend to degenerate with time, and the spread-out arrangement of the gas is messier than the small-volume arrangement.

   ○ b. The quantum wave function of an air molecule extends to the full dimension of the box.

   ○ c. Air molecules repel each other, so they spread out as far as possible.

   ○ d. Of all the ways to arrange the air molecules in a volume, only a small fraction have all the molecules in a smaller sub-volume.

7. (5 points) Heat flows from a body at a higher temperature to a body at a lower temperature. Why? Select the best explanation.

   ○ a. That direction reduces the total energy of the universe.

   ○ b. That direction increases the total energy of the universe.

   ○ c. It is a physical law, which is a fundamental reason to itself.

   ○ d. That direction allows energy to spread out.

[2] Condensing to a liquid or solid doesn't count.

8. An engine burns fuel, absorbing 1672 joules of heat at a temperature of 525°C. It produces 800 joules of work.

   A. (3 points) What is the efficiency of the engine?

   B. (2 points) What quantity of waste heat does the engine expel to the surroundings?

9. Suppose you run a heat pump to extract heat from its 25°C environment to transfer to a high-temperature reservoir at 525°C.

   A. (3 points) What is the greatest possible coefficient of performance of the heat pump?

   B. (2 points) How much work would a maximally performing heat pump need to input 1000 joules of heat into the high temperature reservoir?