Physics 173 Midterm exam

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Read the whole exam, including the information at the end, before you start.

Regular questions:

- Give justification for your answers and clearly state your assumptions.
- For each part of the question please circle or underline your final answer to make it clearly visible to the grader.

1. Suppose someone uses a heat pump to heat their house in the winter, and an air conditioner to cool it in the summer. They are both electrically powered.

   (a) In the winter, the interior of the house will be kept at 72 F and the heat pump will pump heat from the rock deep beneath the house, whose temperature is 45 F. What is the maximum possible efficiency ("COP") of the heat pump?

   (b) Assume the actual COP of the pump is 4.5. The pump is powered by the electricity supply, and the cost of electricity in that city is 14 cents per kiloWatt-hour (kWh). What is the cost of each kiloWatt-hour of heat delivered by the pump to the inside of the house?

   (c) In the winter, the average outside air temperature is about 30 F. Suppose that instead of a geothermal heat pump we used a reversed air conditioner, that pumps heat from the outside air to the inside of the house. What would its maximum possible COP be?

   (d) Which is more efficient, the geothermal heat pump or the reversed air conditioner? Explain in simple terms the reason for this.

   (e) In the summer, the interior of the house will be kept at 77 F and the air conditioner will be used to pump heat from the inside to the outside of the house. The average outside temperature is 95 F. For each kWh of heat energy that is pumped to the outside of the house, what is the minimum number of kWh of work that must be done by the most efficient possible air conditioner?

   (f) For a real air conditioner, the efficiency is only about 10% of the theoretical maximum. In that case, what is the cost of the electricity required to pump 1kWh of heat energy out of the house?

{14 points}

2. Energy delivered by an asteroid impact.
   (a) An asteroid weighs about 10^{12} kg. If its density is twice that of water, roughly what is the size (diameter) of the asteroid, in meters?
   (b) The asteroid travels at a speed of about $10\,\mathrm{km\,s^{-1}}$ relative to the earth. How much kinetic energy (in Joules) would be released if the asteroid hit the earth?
   (c) Convert the previous result to Calories.
   (d) Suppose the asteroid lands in a roughly circular lake, about 10 km across and 10 m deep. If all the asteroid's kinetic energy is converted into heat energy of the water in the lake, by how many degrees Celsius will the lake warm up?
   (e) If the asteroid had been going twice as fast, how would this affect the amount of energy released on impact?

{10 points}

Multiple choice questions **{2 points each}**

1. A Tesla electric car has a battery that holds 80 kWh of energy, whereas the gas tank of a conventional car holds about 500 kWh of energy. If the conventional car has a range of 300 miles on one full tank, what do you expect is the range of the Tesla car on a full charge?
   (A) 50 mi (B) 100 mi (C) 200 mi (D) 400 mi
2. Which of the following features of hybrid cars help them have better gas mileage than regular cars:
   (A) they use regenerative braking
   (B) the battery pack is lighter than a filled fuel tank
   (C) they don't have such good acceleration
   (D) they use a larger capacity engine
3. Which of the following is a significant advantage of hydrogen-powered vehicles over gasoline-powered vehicles?
   (A) hydrogen is not explosive when mixed with air
   (B) hydrogen fuel tanks will be smaller than gasoline tanks
   (C) one can use a variety of energy sources to create the hydrogen
   (D) we can mine naturally-available liquid hydrogen
4. Suppose your electric bill for a whole year is \$1200. Assuming your electricity comes from burning coal, how much coal was burned to supply you with electricity for a year?
   (A) 600 kg (B) 3 tons (C) 6 tons (D) 13 tons

5. When a car crashes into a brick wall, what is a good estimate of the power of the collision?
(A) The kinetic energy of the car
(B) The kinetic energy of the car divided by the amount of time for which the car had been driving
(C) The kinetic energy of the car divided by the mass of the car
(D) The kinetic energy of the car divided by the duration of the collision

6. Which form of energy supplies more than 5% of the U.S.'s total power needs?
(A) nuclear (B) solar (C) wind (D) biomass

7. "Heavy water" is water in which each molecule contains two atoms of deuterium (^{2}H) instead of two atoms of ordinary hydrogen (^{1}H). How much does 1 liter of heavy water weigh?
(A) 1100 g (B) 1200 g (C) 900 g (D) 1050 g

8. The atomic mass of naturally-occurring nitrogen is 14.01. From this you can deduce that
(A) some nitrogen atoms have more than 7 protons
(B) some nitrogen atoms have more than 7 neutrons
(C) naturally-occurring nitrogen contains impurities of other elements
(D) a small fraction of nitrogen atoms clump together to form molecules

9. A sample of mercury contains atoms moving at $200\,\mathrm{m s^{-1}}$. How hot is the sample?
(A) room temperature (B) below 0 C (C) 70 C (D) above 150 C

10. A rod is one foot long at room temperature, but when dropped in boiling water its length increases by 0.1 inches. What is the linear thermal expansion coefficient of the material that the rod is made of?
(A) 0.1 per C (B) 0.1% per C (C) 0.01 per C (D) 0.01% per C

11. A refrigerator is a type of
(A) heat sink (B) heat engine (C) heat pump (D) gravity engine

12. The earth absorbs heat from sunlight. It cools mainly via
(A) convection in the atmosphere
(B) convection in the oceans
(C) emission of visible light
(D) emission of infra-red light

13. The definition of a "greenhouse gas" is a gas that
(A) dissolves easily in ocean water
(B) absorbs infra-red light
(C) nucleates water droplets to form clouds
(D) is transparent to ultra-violet light

Useful quantities

$0\,\mathrm{K} = -273\,\mathrm{C}$ $\quad 0\,\mathrm{C} = 32\,\mathrm{F}$
$100\,\mathrm{C} = 212\,\mathrm{F}$
$M_{\text{nucleon}} = 1.7 \times 10^{-27}\,\mathrm{kg}$

density of gasoline =
0.75 kg per liter

Thermal KE per molecule =
2×10^{-23} Joules/Kelvin

Energy density table

object	Joules/gram	Calories/gram
auto battery	140	0.03
Lithium-ion battery	400	0.1
TNT	4200	1
butter	29000	7
coal	27000	6
gasoline/oil	42000	10
natural gas	54000	13
Hydrogen liquid or gas	110000	26
Uranium-235	82 billion	20 million

Elements

Name	symbol	atomic number	atomic mass
Hydrogen	H	1	1.008
Carbon	C	6	12.01
Nitrogen	N	7	14.01
Oxygen	O	8	16.00
Chlorine	Cl	17	35.45
Iron	Fe	26	55.85
Mercury	Hg	80	200.6
Uranium	U	92	238.02