

## 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. Estimating the power output of a wind turbine.
    - (a) The General Electric “1.5MW” wind turbine has rotor blades that are 116 feet long, so the area swept by the blades is a circle of radius 116 ft. What is this area in square meters?
    - (b) If the turbine is positioned facing a 20 mile per hour wind, what volume (in cubic meters) of air passes through the turbine (through the area swept by the blades) in one second?
    - (c) What is the kinetic energy of that air, in Joules? (The density of air is 1.2 grams per liter.)
    - (d) If the turbine is able to convert 10% of the air’s kinetic energy in to electricity, what is the power output of the turbine, in Watts?
    - (e) If the turbine maintained this power output continuously, roughly how many turbines would it take to supply the electrical power needs of a city of 100,000 houses?

**{10 points}**

2. Suppose you use a geothermal heat pump as the water heating system for your house in Alaska.
  - (a) The water will be kept at 170 F. What is that in Celsius and Kelvin?
  - (b) The heat pump will pump heat from the rock deep beneath the house, whose temperature is 50 F. What is that in Celsius and Kelvin?
  - (c) What is the maximum possible efficiency of the heat pump?
  - (d) Assume the actual efficiency of the pump is 3.0. The pump is powered by the electricity supply, and the cost of electricity in Alaska is about 17 cents per kiloWatt-hour. What is the approximate cost of each kiloWatt-hour of heat delivered by the heat pump?
  - (e) A neighbor tells you he is building a new house. He is trying to decide whether to use a natural gas heater or a geothermal heat pump for his hot water system. If natural gas costs about 5¢per kWh, what advice would you give him?

- (f) The neighbor is also trying to decide whether to use natural gas or a geothermal heat pump to heat his home. What advice would you give him? Justify your answer with a numerical estimate.

{12 points}

**Multiple choice questions**

**{2 points each}**

- Which of the following sentences uses incorrect units?  
(A) A typical wine bottle holds a volume of about 0.75 liters  
(B) This battery stores 0.06 kWh of energy  
(C) The density of gasoline is about 0.75 kg  
(D) The power in sunlight is about 1 kW per square meter
- When someone says “the energy density of gasoline is about 10 Calories per gram”, what they mean is  
(A) when a gram of gasoline is oxidized to carbon dioxide and water, it gives out 10 Cal of energy  
(B) it takes 10 Cal of energy to extract a gram of gasoline from crude oil  
(C) when a gram of gasoline evaporates, it gives out 10 Cal of energy  
(D) in order for a gram of gasoline to evaporate, it must absorb 10 Cal of energy
- Roughly how much butter would have 1 kWh of chemical energy?  
(A) 20 g      (B) 0.8 kg      (C) half a pound      (D) 120 g
- How many kiloWatt-hours of chemical energy are stored in a typical gasoline-powered car’s full tank of gasoline?  
(A) 5      (B) 500      (C) 5000      (D) 50
- A hybrid car’s battery stores about 9 kWh of energy. Estimate how far the car can travel on a fully charged battery, without using any other energy source.  
(A) 40 miles      (B) 20 miles      (C) 12 miles      (D) 4 miles
- A golf cart battery holds about 1 kWh of energy. At an open air concert, the band uses the golf cart to power their sound system, which consumes 200 W, and their light show, which consumes 300 W. For how long can the band play?  
(A) 2 hours      (B) 3 hours      (C) 1 hour      (D) 20 minutes
- Blue hydrogen is  
(A) made from natural gas, producing CO<sub>2</sub> which is stored underground  
(B) made from natural gas, releasing CO<sub>2</sub> in to the atmosphere  
(C) extracted from natural underground deposits of hydrogen gas  
(D) made from water using energy from low-carbon sources

8. When a cyclist is travelling on a flat road at a constant speed, the power provided by her legs,
- (A) is roughly the cyclist's kinetic energy divided the time it takes for the wheels to make one rotation
  - (B) is roughly the cyclist's kinetic energy divided by how long she has been riding
  - (C) mainly ends up creating heat
  - (D) causes her kinetic energy to steadily increase
9. Which form of energy supplies more than 10% of the U.S.'s total power needs?
- (A) biofuels
  - (B) wind
  - (C) coal
  - (D) natural gas
10. For each kWh of electrical energy produced by a coal-burning power plant, how many kWh of the coal's chemical energy go unused ("wasted")?
- (A) 2 kWh
  - (B) 3 kWh
  - (C) none
  - (D) 1 kWh
11. "Heavy water" is water in which each molecule contains two atoms of deuterium ( $^2\text{H}$ ) instead of two atoms of ordinary hydrogen ( $^1\text{H}$ ). How much does 1 liter of heavy water weigh?
- (A) 1100 g
  - (B) 1200 g
  - (C) 1012 g
  - (D) 1050 g
12. Air consists of nitrogen molecules ( $\text{N}_2$ ), oxygen molecules ( $\text{O}_2$ ), and carbon dioxide molecules ( $\text{CO}_2$ ). Which of these is the correct ordering from fastest moving to slowest moving?
- (A) nitrogen, oxygen, carbon dioxide
  - (B) oxygen, carbon dioxide, nitrogen
  - (C) carbon dioxide, oxygen, nitrogen
  - (D) nitrogen, carbon dioxide, oxygen
13. The linear expansion coefficient of olive oil is 0.0002 per C. Suppose olive oil in a non-expanding bottle is heated so that the depth of oil increases from 8 inches to 8.1 inches. By how much did the temperature of the olive oil change when it was heated?
- (A) 500 C
  - (B) 60 C
  - (C) 20 C
  - (D) 7 C
14. If an electric heat pump's coefficient of performance is 4.0, that means that for every Joule of heat it produces,
- (A) it consumes 4 J of electricity
  - (B) it consumes 0.25 J of electricity
  - (C) it takes 3 J from the cold reservoir
  - (D) it takes 0.25 J from the cold reservoir

### Useful quantities

$$0\text{ K} = -273\text{ C} \quad 0\text{ C} = 32\text{ F}$$

$$100\text{ C} = 212\text{ F}$$

$$M_{\text{nucleon}} = 1.7 \times 10^{-27}\text{ kg}$$

$$\text{Thermal KE per molecule} = \\ 2 \times 10^{-23}\text{ J/K}$$

### 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
Deuterium	$^2\text{H}$	1	2.014
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