

Physics 173, Physics of Sustainable Energy
Homework 1
Due: 1pm Tues Sept 5, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular question

When you write out your response, please circle or underline the final answer to each part of the question. This will make it clearly visible to the grader. Remember to give justification for all your answers, and whenever the answer is a number always show the units, e.g. “200 J”, “0.5 kg”.

1. The current price of crude oil is about \$85/barrel. A barrel of crude oil is 42 gallons and weighs about 300 lbs.
 - (a) What is the current price of crude oil in dollars per liter?
 - (b) What is the density of crude oil in kg/liter?
 - (c) The current price of coal is about \$150 per ton. What is that in dollars per kilogram?
 - (d) In terms of price per unit weight, is oil cheaper or more expensive than coal, and by what factor?

{8 points}

Multiple choice questions

{2 points each}

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. Which of the following sentences uses incorrect units?
 - (A) A car weighs about a ton
 - (B) My front door is only 90 cm wide
 - (C) A typical wine bottle holds a volume of about 0.75 liters
 - (D) The density of gasoline is about 0.75 kg
2. Which of the following is not a unit of density?
 - (A) kilograms per cubic inch
 - (B) pounds per liter
 - (C) pounds per foot
 - (D) grams per milliliter
3. Roughly how much does the air in a small room weigh?
 - (A) 200 g (B) 2 mg (C) 200 mg (D) 20 kg

4. The gas tank of a car is 80 cm long, 30 cm wide, and 20 cm high. Roughly how many gallons of gas can it hold?
(A) 24 gal (B) 12 gal (C) 48 gal (D) 36 gal
5. A NASCAR racecar has an engine capacity of 358 cubic inches. What is that in liters?
(A) 6 liters (B) 900 liters (C) 140 liters (D) 0.3 liters
6. The fact that energy is conserved means that
(A) energy is never created or destroyed
(B) the chemical energy of an object is equal to its kinetic energy
(C) thermal energy cannot be converted into any other form of energy
(D) when energy changes form you always lose a significant fraction of it
7. Brenda throws a package from the front porch of her house up through the second floor window where it is caught by her brother. Which of the following energy transformations have occurred in this process?
(A) thermal energy of the package to gravitational potential energy of Brenda's body
(B) kinetic energy of the package to gravitational potential energy of the package
(C) gravitational potential energy of the package to chemical energy of the package
(D) gravitational potential energy of Brenda's brother to chemical energy in the package
8. When you burn natural gas to heat your house, the main energy transformation is
(A) thermal energy is being converted to electrical energy
(B) electrical energy is being converted to thermal energy
(C) electrical energy is being converted to chemical energy
(D) chemical energy is being converted to thermal energy

Physics 173, Physics of Sustainable Energy
Homework 2

Due: 1pm Tues Sept 12th, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular question

When you write out your response, please circle or underline the final answer to each part of the question. This will make it clearly visible to the grader.

Remember to give justification for all your answers, and whenever the answer is a number always show the units, e.g. “200 J”, “0.5 kg”.

1. Your friend has a swimming pool that is 20 feet long, 10 feet wide, and 5 feet deep. It is heated by a heating system that burns oil, supplied by an oil tank containing about 100 gallons of oil (which has the same density and energy density as gasoline).
 - (a) Estimate how much energy in Calories is needed to heat the pool at the start of the season. Your friend says he heats his pool to 86 F. You'll have to make a reasonable estimate of the temperature of the cold water that is in the pool before he starts heating it.
 - (b) Estimate how many gallons of oil must be burned to heat the water at the start of the season.
 - (c) Your friend says that heating the water at the start of the season uses up most of the oil in the tank. Is this consistent with your calculation? If not, what are plausible reasons for any discrepancy?
 - (d) Your friend is thinking of switching to an electric heater to heat his pool. What would be the cost of the electricity needed to heat his pool at the start of the season?

{12 points}

Multiple choice questions

{2 points each}

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. What is the U.S.'s total annual energy consumption, in kiloWatt-hours?
(A) 3×10^{11} kWh (B) 2×10^{14} kWh (C) 3×10^{13} kWh (D) 2×10^{12} kWh
2. To within 20% accuracy,
(A) a Calorie is the same as a Watt-hour
(B) a British Thermal Unit is the same as a kiloWatt-hour
(C) a Watt-hour is the same as a British Thermal Unit
(D) a kilojoule is the same as a kiloWatt-hour

3. Batteries are a popular way to store energy because
- (A) they provide electrical energy which is convenient to use
 - (B) they provide thermal energy which is convenient to use
 - (C) they have a high energy density compared to food or fuel
 - (D) they have a low energy density compared to food or fuel
4. A typical alkaline AA battery weighs about 20 g. Estimate how much energy it contains. Roughly (to within a factor of 2) how much would this amount of electrical energy cost if it was obtained from the electrical outlets in your home?
- (A) 0.3 cents (B) 10 cents (C) 0.03 cents (D) 1 cent
5. The current price of gasoline in China is about \$1.20 per liter. How much are Chinese motorists paying for each kiloWatt-hour of chemical energy when they buy gasoline?
- (A) \$2/kWh (B) 5 ¢/kWh (C) 40 ¢/kWh (D) 15 ¢/kWh
6. Which of the following is a true statement about ways to store energy:
- (A) hydrogen has a higher energy density than gasoline
 - (B) batteries have a higher energy density than butter
 - (C) uranium has a lower energy density than gasoline
 - (D) coal has about the same energy density (to within 20%) as an explosive like TNT
7. 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
8. Which of the following is a major disadvantage of electric cars compared to gasoline cars?
- (A) batteries have a lower energy density than gasoline
 - (B) batteries explode more readily than gasoline
 - (C) electric motors are more efficient than gasoline engines
 - (D) in terms of price per kWh, electrical energy is much more expensive than gasoline
9. In a heating system that runs on natural gas, what volume of natural gas is needed to produce 1 kWh of heat? (The density of methane is 0.6 g/liter).
- (A) 1 ft³ (B) 4 ft³ (C) 40 ft³ (D) 10 ft³

Physics 173, Physics of Sustainable Energy
Homework 3
Due: 1pm Tues Sept 19, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Short report **{20 points}**

Write a short critical summary (about 300 words) of a recent published article which is related to the topics covered so far the course, namely energy storage, different types of car, fuels, etc. You can choose the article but first read the instructions for writing the report which are on the course web page in the “Materials” tab.

Using AI tools such as ChatGPT: You are allowed to use an AI tool to help you with your short report; if you do that, please provide additional information as described in the instructions.

Piazza: If you are unsure about your choice of article or use of AI tools or have other questions, you can post on the Piazza page,
<https://piazza.com/wustl/fall2023/f12023131physics17301>

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

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. A traditional gasoline-powered lawnmower can mow half an acre of land using about a gallon of gasoline. For an electric lawn mower to mow the same area on a full charge, what would be the weight of its Lithium-ion battery pack?
(A) 150lb (B) 220lb (C) 2.7 kg (D) 270 kg
2. Which of the following is *not* true of a standard hybrid car (like a Toyota Prius)?
(A) there is a gasoline tank
(B) the battery needs to be plugged in to an electrical outlet in order to charge it
(C) there is a gasoline engine and electric motor
(D) regenerative braking helps to recharge the battery
3. A hydrogen-powered car contains
(A) a fuel cell and a gasoline tank
(B) a gasoline engine and an electric motor
(C) a fuel cell and an electric motor
(D) a battery and a gasoline tank
4. What is the main difference between burning hydrogen in a car-type engine and oxidizing it in a fuel cell?
(A) the engine produces CO₂ but the fuel cell does not
(B) the engine produces electricity but the fuel cell does not

- (C) the fuel cell produces CO_2 but the engine does not
(D) the fuel cell produces electricity but the engine does not
5. Which of these is a significant disadvantage of hydrogen-powered automobiles compared to gasoline-powered ones?
(A) hydrogen fuel cells are less efficient than gasoline engines
(B) hydrogen is difficult to transport and store
(C) hydrogen is radioactive and the public fears it
(D) unlike gasoline, hydrogen mixed with air is dangerously explosive
6. The energy density of methanol is about half that of gasoline. Using your knowledge of the efficiency of fuel cells versus gasoline engines, how many miles would you expect a methanol-powered car could travel on a gallon of methanol? (The density of methanol is similar to gasoline)
(A) 50 miles (B) 20 miles (C) 5 miles (D) 1 mile
7. A methanol powered car produces CO_2 when it runs. Does that mean it is contributing to global warming?
(A) No, if the methanol was produced from recently living biomass
(B) Yes, if the methanol was produced from recently living biomass
(C) Yes, if the methanol was produced from solar power
(D) No, if the methanol was produced from natural gas.
8. The density of compressed natural gas is 60 grams per liter. If a car were powered by an engine that burned natural gas (similar to a gasoline engine), how large a compressed natural gas tank would it need to have the same range as a standard gasoline car?
(A) about 3 times bigger than a standard car's gasoline tank
(B) about the same as a standard car's gasoline tank
(C) about 20 times bigger than a standard car's gasoline tank
(D) about 10 times bigger than a standard car's gasoline tank
9. For each kWh of electrical energy produced by a natural-gas-burning power plant, how many kWh of heat energy go unused ("wasted")?
(A) 2 kWh (B) 3 kWh (C) none (D) 1 kWh
10. Based on the numbers given in the "Marginal cost of energy" lecture slide, how much coal does it take to generate 1 kWh of electricity?
(A) 100 lb (B) 5 kg (C) 1 lb (D) 50 g

Physics 173, Physics of Sustainable Energy
Homework 4

Due: 1pm Tues Sept 26th, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular question

When you write out your response, please circle or underline the final answer to each part of the question. This will make it clearly visible to the grader.

Remember to give justification for all your answers, and whenever the answer is a number always show the units, e.g. “200 J”, “0.5 kg”.

1. In this question we will estimate the energy released in the 9/11 terrorist attack on the world trade center.
 - (a) A fully-laden Boeing 767 airplane weighs about 100 tons. How much is that in kilograms?
 - (b) Explain which one of the following is the best estimate of the speed (in meters/second) at which the airplane flew in to the world trade center: 10 m/s; 50 m/s; 200 m/s.
 - (c) Using your answer from the previous part, roughly how much kinetic energy (in Joules) was released when the plane hit the tower? How many tons of TNT would one have to detonate to release the same amount of energy?
 - (d) If the airplane had been going twice as fast, how would this affect the amount of kinetic energy released?
 - (e) A Boeing 767 carries about 25 tons of jet fuel, whose chemical energy content is similar to that of gasoline. If that fuel burned completely after the collision, how much chemical energy in Joules was released? How many tons of TNT is that equivalent to?
 - (f) Make a reasoned estimate of which had higher power, the release of kinetic energy or the release of chemical energy.

{14 points}

Multiple choice questions

{2 points each}

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. Compared to gasoline, hydrogen has
 - (A) higher energy density per unit volume and per unit mass
 - (B) higher energy density per unit volume but lower energy density per unit mass
 - (C) lower energy density per unit volume but higher energy density per unit mass
 - (D) lower energy density per unit volume and per unit mass

2. A new hydroelectric power plant proposed for the Mississippi River near St. Louis is advertised as “delivering 438,000 megawatt-hours of renewable electricity to the region annually”. What is the average power output of the plant?
(A) 50 MW (B) 1.2 GW (C) 438 GW (D) 438 MW
3. A car accelerates from 0 to 60 miles/hour in 6 seconds. What is a good estimate of the power output of the engine?
(A) the mass of the car divided by 60 miles
(B) the chemical energy of the gasoline consumed during the acceleration
(C) the thermal energy produced by the engine during the acceleration
(D) the final kinetic energy of the car divided by 6 seconds
4. If you use a 1 kW electric toaster oven to cook a pizza, which takes 20 minutes, what is the approximate cost of the electricity consumed?
(A) 90¢ (B) 20¢ (C) 3¢ (D) 1¢
5. A large power plant can provide enough electricity to power, on average, about
(A) a million homes (B) 10,000 homes (C) 1000 homes (D) 100,000 homes
6. Which of the following statements about the levelized cost of generating electricity is correct?
(A) solar rooftop panels on a house are cheaper than a coal power plant
(B) wind power is cheaper than nuclear power
(C) large solar power plants (“utility scale”) are more expensive than coal
(D) solar thermal power is the cheapest form of solar power
7. A large animal’s body produces about 1 horsepower in the form of heat. Roughly (to within 20%) how many food Calories does this require the animal to eat in a day?
(A) 60,000 Cal (B) 15,000 Cal (C) 8 million Cal (D) 20 Cal
8. Which of the following is a true statement about the role of electrical power in the U.S.?
(A) electricity generation is responsible for more than 1/3 of our total energy consumption
(B) most of our electricity comes from burning natural gas
(C) most of our electricity comes from burning coal
(D) the average electricity generating power station is about 50% efficient

Physics 173, Physics of Sustainable Energy
Homework 5
Due: 1pm Tues Oct 3rd, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Short report **{20 points}**

Write a short critical summary (about 300 words) of a recent published article which is related to one of the topics covered in recent lectures, namely power, heat, kinetic energy, temperature, thermal expansion etc. You can choose the article but first read the instructions for writing the report which are on the course web page in the “Materials” tab.

Using AI tools such as ChatGPT: You are allowed to use an AI tool to help you with your short report; if you do that, please provide additional information as described in the instructions.

Piazza: If you are unsure about your choice of article or use of AI tools or have other questions, you can post on the Piazza page,
<https://piazza.com/wustl/fall2023/f12023l31physics17301>

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

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. Based on the energy density table that we studied earlier in the course, estimate how fast the internal parts of an energy-storage flywheel are travelling.
(A) 500 mi/hr (B) 20 mi/hr (C) 100 mi/hr (D) 5 mi/hr
2. 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
3. The diameter of a nucleus in an atom is (to within a factor of 5)
(A) 100 times smaller than the diameter of the atom
(B) too small for scientists to measure
(C) about 1% of the diameter of an atom
(D) 100,000 times smaller than the diameter of the atom
4. The atomic mass of a mystery molecule is 114. What is a possible chemical formula for the molecule?
(A) C₈ H₁₈ (B) C₈O₂ H₁₀ (C) C₁₈ H₁₈ (D) C₁₈ O₂ H₈

5. The atomic mass of naturally-occurring chlorine is 35.45. From this you can deduce that
- (A) naturally-occurring chlorine contains impurities of other elements
 - (B) a small fraction of chlorine atoms clump together to form molecules
 - (C) some chlorine atoms have more than 17 protons
 - (D) some chlorine atoms have more than 17 neutrons
6. Air consists of nitrogen molecules (N_2), oxygen molecules (O_2), and carbon dioxide molecules (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
7. A jug of water is at the same temperature as the air around it. This means that the molecules in the water and in the air have the same
- (A) atomic mass
 - (B) average kinetic energy
 - (C) average velocity
 - (D) average velocity-squared.
8. When you cool an object from room temperature (20 C) to freezing (0 C), its thermal energy
- (A) decreases to zero
 - (B) decreases by about 25%
 - (C) stays about the same
 - (D) decreases by about 10%
9. 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
10. Lake Michigan's average depth is about 100 m. If the temperature of the water increases by 2.5 C, by how much will its depth change?
(Linear expansion coeff of the water is $5 \times 10^{-5} \text{C}^{-1}$)
- (A) 0.5 cm (B) 12 cm (C) 1.2 cm (D) 4 cm

Physics 173, Physics of Sustainable Energy
Homework 6
Due: 1pm THURS Oct 12th, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular question

1. A company called PowerPocket is developing a cell phone charger that is powered by the heat of the human body. Please see this article: <https://newatlas.com/power-pocket-charger/27914/>. The idea is to use the “Seebeck effect” which is basically a heat engine that turns the human body’s output of heat into electrical energy. We will analyse the performance of a PowerPocket charger sewn into the hip pocket of jeans (see the second picture in the article).
 - (a) Estimate the maximum possible efficiency of a portable heat engine that, when worn in regular indoor environments, converts human body heat to electricity.
 - (b) Now we are going to estimate the heat power flowing into the charger so we can estimate the electrical power it could produce. Give a reasoned estimate of the heat power output of a human body at rest.
 - (c) Estimate the total surface area of the human body, assuming it can be approximated as a cylinder of height 5 feet and “waistline” (circumference) 35 inches. You can ignore the top and bottom “endcaps” of the cylinder. Give your result in square *centimeters*.
 - (d) Using the results you have calculated above, estimate (in Watts) the heat power that could be flowing into the charger, which is the size of a hip pocket.
 - (e) Using your answer to part (a), estimate the electrical power output from the charger.
 - (f) A typical cell phone battery can hold about 5 Watt-hours of energy. Estimate how long would it take for the body-heat charger to charge up a cell phone battery.
 - (g) Give a well-reasoned comment on the practicality of the PowerPocket charger, and suggest how it could be improved.

{14 points}

Multiple choice questions

{2 points each}

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1. At 0 C, ice floats on water because
 - (A) ice is denser than water
 - (B) the surface gets cold first so that is where ice forms
 - (C) the surface tension of ice is greater than that of water
 - (D) water is denser than ice
2. Which of the following is true:
 - (A) heat pumps can have an efficiency of more than 100%
 - (B) a heat engine's main purpose is to use work to drive heat from a cold object to a hot one
 - (C) heat engines can have an efficiency of more than 100%
 - (D) a heat pump needs a large temperature difference in order to work efficiently
3. In a Carnot-cycle-type heat pump, when heat is emitted to the surroundings,
 - (A) the refrigerant is leaking out into the surroundings
 - (B) the refrigerant is being compressed
 - (C) the expansion valve is closed
 - (D) the pressure of the refrigerant is decreasing
4. Suppose that in winter you flip your window air-conditioner around so that it can act as a heat pump to heat your house. What is its maximum possible efficiency ("COP") (to 20% accuracy)? You want to keep your house at 70 F, and the typical air temperature outside in winter is around freezing.
 - (A) 3
 - (B) 23
 - (C) 1.5
 - (D) 15
5. Your house is heated by a heat pump with a CoP of 4.5, and the cost of electricity in your city is 18 /kWh. What are you paying for each kiloWatt-hour of heat?
 - (A) 2¢
 - (B) 4¢
 - (C) 6¢
 - (D) 12¢
6. During the last 100 years, global average sea level
 - (A) has risen more than 10 cm
 - (B) fluctuated around a roughly constant value
 - (C) rose at first and is now falling again
 - (D) fell between 5 and 10 cm
7. We can estimate what earth's temperature was *hundreds of thousands* of years ago by
 - (A) consulting written records of weather and agricultural activity
 - (B) sampling air bubbles trapped in ancient ice
 - (C) measuring separation between tree rings in old trees
 - (D) sampling water from the deepest levels of the ocean
8. Which of the following is a true statement?
 - (A) during the last 10 years, each year had a higher global average temperature than the year before.
 - (B) during the "little ice age", global average temperature was more than 1 C cooler than during the medieval warm period
 - (C) over the last 20 years, the Greenland ice sheet has lost between 4 and 5 billion tons of ice
 - (D) over the last 100 years, average sea level has risen by about 20 cm

Physics 173, Physics of Sustainable Energy
Homework 7
Due: 1pm Tues Oct 31, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular question

When you write out your response, please circle or underline the final answer to each part of the question. This will make it clearly visible to the grader. Remember to give justification for all your answers, and whenever the answer is a number always show the units, e.g. “200 J”, “0.5 kg”.

1. Imagine a solar system with a sun that is the same brightness as our sun, but with different planets going around it. One of the planets is called Arrakis. On Arrakis, the power per unit area in sunlight is $F = 2200 \text{ Wm}^{-2}$, the absorption fraction for sunlight is $\alpha = 0.65$ and the infra-red emissivity is $\epsilon = 0.75$.
 - (a) Is Arrakis closer to its sun than Earth is to our sun, or further away? Give reasons for your answer.
 - (b) Using the simple model studied in class, estimate the average surface temperature of Arrakis, in Kelvin, Celsius, and Fahrenheit. How easy would it be for humans to live on Arrakis?
 - (c) Suppose that we wanted to modify the climate of Arrakis by making its average temperature the same as Earth's (57 F). We plan to do this by modifying its infra-red emissivity. What value of the emissivity should we aim for?
 - (d) Suggest and justify one possible way of modifying Arrakis's atmosphere that would move its temperature in the desired direction.

{8 points}

2. For the planet Arrakis discussed in the previous question, suppose its climate has a feedback mechanism such that the absorption fraction is itself a function of temperature: $\alpha = (197 \text{ K})/T$ where T is the average surface temperature of Arrakis in Kelvin.
 - (a) Is this positive feedback or negative feedback? Explain why.
 - (b) Give and explain an example of a climate phenomenon that could cause such a feedback effect.
 - (c) If we include that feedback mechanism in our model, what emissivity should we aim for to get the surface temperature to the same value as Earth's?

{6 points}

Multiple choice questions

{2 points each}

1. According to the Milankovitch theory, the cycle of ice ages and interglacial warm periods is caused by
 - (A) variations in the brightness of the sun
 - (B) comets depositing reflective materials in the earth's atmosphere
 - (C) seismic activity growing and shrinking the polar ice caps
 - (D) variations in the shape of earth's orbit around the sun
2. If the snow caps at the poles melt, the main direct effect of this is
 - (A) reduce earth's absorption fraction
 - (B) increase earth's absorption fraction
 - (C) decrease the solar constant
 - (D) decrease earth's emissivity
3. Which of the following is not a greenhouse gas?
 - (A) nitrous oxide
 - (B) nitrogen
 - (C) methane
 - (D) carbon dioxide
4. Water vapor is a greenhouse gas. So why don't we count emissions of water vapor from cars, power plants, etc, as GHG emissions?
 - (A) water vapor has a short lifetime: any extra water vapor we add to the atmosphere quickly condenses out, e.g. into oceans or rainfall
 - (B) the GHG effects are cancelled by the formation of clouds that reflect sunlight
 - (C) neglecting those emissions is a mistake, they should be counted
 - (D) global warming means that there is less water vapor in the atmosphere
5. According to models of climate,
 - (A) a rise in CO_2 can cause a rise in temperature, but not vice versa
 - (B) a rise in temperature can cause a rise in CO_2 , but not vice versa
 - (C) temperature and CO_2 are uncorrelated
 - (D) a rise in CO_2 can cause a rise in temperature, and vice versa
6. Which of the following has increased significantly in the last 50 years?
 - (A) the severity of droughts (Palmer drought severity index)
 - (B) the annual count of strong tornadoes
 - (C) the share of U.S. land area experiencing unusually high summer temperatures
 - (D) The number of category 1 or 2 hurricanes occurring every year
7. The solar constant $F = 1365 \text{ Wm}^{-2}$ is more than our usual estimate of the power in sunlight arriving on earth's surface, 1 kWm^{-2} , because
 - (A) the solar constant is for a wider range of wavelengths
 - (B) solar panels have an efficiency of less than 100%
 - (C) the solar constant is the power in sunlight above the atmosphere
 - (D) 1 kWm^{-2} is the average over one day
8. If we removed all greenhouse gases from the atmosphere,
 - (A) the earth's temperature would probably fall
 - (B) the solar constant F would probably fall
 - (C) this would make the atmosphere unbreathable
 - (D) the solar constant F would probably rise

Physics 173, Physics of Sustainable Energy
Homework 8
Due: 1pm, Tues Nov 7th, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Short report **{20 points}**

Write a short critical summary (about 300 words) of a recent published article which is related to the topics covered in recent lectures, such as climate change, fossil fuels, etc. You can choose the article but first read the instructions for writing the report which are on the course web page in the “Materials” tab.

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

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. If the Earth's emissivity and absorption fraction both increase, then the overall effect on global average temperature will be
 - (A) global average temperature will rise
 - (B) global average temperature will fall slowly
 - (C) global average temperature will fall quickly
 - (D) it is impossible to say from just this information
2. According to models of climate,
 - (A) a rise in CO₂ can cause a rise in temperature, but not vice versa
 - (B) a rise in temperature can cause a rise in CO₂, but not vice versa
 - (C) temperature and CO₂ are uncorrelated
 - (D) a rise in CO₂ can cause a rise in temperature, and vice versa
3. Which of the following has increased significantly in the last 50 years?
 - (A) the severity of droughts (Palmer drought severity index)
 - (B) the share of U.S. land area experiencing unusually high summer temperatures
 - (C) the annual count of strong tornadoes
 - (D) The number of category 1 or 2 hurricanes occurring every year
4. Water vapor is a greenhouse gas. So why don't we count emissions of water vapor from cars, power plants, etc, as GHG emissions?
 - (A) the GHG effects are cancelled by the formation of clouds that reflect sunlight
 - (B) neglecting those emissions is a mistake, they should be counted
 - (C) water vapor has such a short lifetime that our emissions don't significantly change the amount in the atmosphere
 - (D) global warming means that there is less water vapor in the atmosphere

5. We can measure the mass of the Antarctic ice cap by
(A) using satellites that measure its gravitational field
(B) drilling ice cores and examining the trapped air bubbles
(C) measuring changes in global average sea level
(D) analysing the spectrum of the light that it reflects
6. In 1920, the average power consumption by people across the world was
(A) mostly supplied by biofuels
(B) about half of what it is today
(C) about the same as today
(D) mostly supplied by oil and natural gas
7. If we wanted to reduce the methane in Earth's atmosphere from its current level of about 1700 ppb (parts per billion) to its pre-industrial level of about 500 ppb, how many tons of methane would we have to remove from the atmosphere? (Mass of atmosphere is 5×10^{15} tons.)
(A) 6 billion tons (B) 9 billion tons
(C) 6 trillion tons (D) 9 trillion tons
8. Over the next 40 years, the biggest contribution to the growth in global energy consumption will come from
(A) Asia (B) Africa (C) Europe (D) the Middle East
9. Over the next 5 years, India's annual electrical power consumption is expected to rise from about 2500 kWh/yr/person to about 3500 kWh/yr/person. To meet this demand, how many 1 GW power stations will India have to build?
(Feel free to look up India's population online.)
(A) 50 (B) 500 (C) 150 (D) 1500
10. When oil (e.g. gasoline) is burned, how much CO₂ is produced per kWh of energy released?
(A) 0.26 kg/kWh (B) 0.54 kg/kWh
(C) 0.18 kg/kWh (D) 0.12 kg/kWh

Physics 173, Physics of Sustainable Energy
Homework 9
Due: 1pm, Tues Nov 14, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular question

When you write out your response, please circle or underline the final answer to each part of the question. This will make it clearly visible to the grader. Remember to give justification for all your answers, and whenever the answer is a number always show the units, e.g. “200 J”, “0.5 kg”.

1. Estimating future energy needs of China

- (a) If someone uses 8000 kWh of energy per year, what is their average power consumption in kilo-Watts?
- (b) What is the population of China?
- (c) Suppose that over the next 10 years, China’s GDP is expected to rise from \$12,000 per person per year to \$20,000 per person per year. Using the relation between per capita GDP and power consumption discussed in class, estimate how much the rate of power consumption for the whole of China will increase between now and 2033. Give your answer in GW.
- (d) Suppose 40% of this extra demand is for electrical power. How many new 1 GW power stations would China have to build per week during the next 10 years to meet the extra demand for electrical power?

{8 points}

2. (a) Make a well-reasoned estimate of how many tons of CO₂ per year are produced by a 1 GW coal-fired power plant.
- (b) Describe the advantages and disadvantages of carbon capture and sequestration as an approach to combating global warming

{6 points}

Multiple choice questions

{2 points each}

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. In terms of the simple climate model we discussed in class, geoengineering to combat global warming typically involves
- (A) Increasing α or increasing ε

- (B) Increasing α or decreasing ε
 - (C) Decreasing α or increasing ε
 - (D) Decreasing α or decreasing ε
2. Which of these regions is currently producing the most carbon dioxide per year?
- (A) Africa (B) The European Union countries
 - (C) India (D) The United States
3. Fossil fuels
- (A) are becoming more expensive over the last 10 years
 - (B) provide less than 50% of the U.S.'s total power needs
 - (C) have a higher energy density than batteries
 - (D) are mostly found in developing countries
4. Which of the following is the most significant likely consequence of global warming?
- (A) growth in average income of people in China and India
 - (B) famines due to crop failure
 - (C) population becoming more concentrated into mega-cities
 - (D) increased rate of cancer deaths
5. Hydraulic fracturing ("fracking") uses water and sand to
- (A) extract oil or gas from rock
 - (B) extract hydrogen from water
 - (C) deposit carbon dioxide in underground shale vaults
 - (D) drill deeper than was previously possible
6. Using natural gas to provide energy
- (A) creates no GHG
 - (B) creates less GHG per kWh than using coal
 - (C) is not suitable for the USA because we lack natural gas deposits
 - (D) creates more GHG per kWh than using oil
7. Which of the following is an example of efficiency as a way of reducing energy consumption?
- (A) carbon capture and storage
 - (B) putting a tax on fossil fuels
 - (C) converting coal into synthetic liquid fuel
 - (D) improving the fuel economy of cars
8. A nuclear power plant is powered by
- (A) heat from fission of nuclei
 - (B) alpha particles from fission of nuclei
 - (C) heat from fusion of nuclei
 - (D) heat from burning (oxidation) of ^{235}U

Physics 173, Physics of Sustainable Energy
Homework 10
Due: 1pm, Tues Nov 21, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Short report **{20 points}**

Write a short critical summary (about 300 words) of a recent published article which is related to the topics covered in recent lectures, namely energy consumption and production. You can choose the article but first read the instructions for writing the report which are on the course web page in the “Materials” tab.

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

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. Which of the following ways of generating electricity is *not* a heat engine?
(A) a nuclear power plant
(B) a coal power plant
(C) a geothermal electric power plant
(D) a solar panel
2. A house is heated by an electrically powered geothermal heat pump. Over the 4 months of winter, the total electricity bill is \$1200. Which of the following is a reasonable estimate of the power output of the heat pump?
(A) 15 kW (B) 60 kW (C) 1 kW (D) 160 kW
3. Which of these is a positive feature of nuclear (fission) power?
(A) there are no harmful waste products
(B) the fuel is renewable and costs nothing
(C) nuclear power plants are potential targets for terrorists
(D) nuclear power production does not emit greenhouse gases
4. If a 200 MW fusion reactor runs for a year, how much helium will it produce? (Each fusion event ($^2\text{H} + ^3\text{H} \rightarrow \text{He} + \text{n}$) produces about 10^{-12} J of electrical energy.)
(A) 4 kg (B) 20 kg (C) 200 kg (D) 40 kg
5. Which of the following are good ways to overcome the intermittency of wind power?
(A) dumping the excess energy as heat in the ocean
(B) telling people not to consume electricity when the wind is weak
(C) storing the generated energy
(D) building larger turbines

6. A wind turbine has blades that are 5 meters long. In a 40 mile per hour wind, which of these is a reasonable estimate of the maximum possible power output of the turbine? (The density of air is 1.2 kg/m^3 .)
(A) 50 kW (B) 150 kW (C) 250 kW (D) 500 kW
7. Watch the “How do solar panels work?” video on the course website. According to the video, solar panels consist mostly of
(A) silicon and oxygen
(B) two forms of silicon, n-type and p-type
(C) two different isotopes of germanium
(D) glass that is transparent to ultraviolet light
8. Watch the “How do solar panels work?” video on the course website. According to the video, what is the efficiency of the best solar cells currently available?
(A) 46% (B) 24% (C) 15-20% (D) 35%
9. How big an area of typical solar panels, in full sunlight, would produce the power needed to run a car?
(A) 500 m^2 (B) 100 m^2 (C) 50 m^2 (D) 10 m^2
10. Roughly how much energy would you have to store in order to power the Greater St. Louis metropolitan area for 12 hours?
(A) 100 GWh (B) 1 GWh (C) 10 GWh (D) 1 TWh

Physics 173, Physics of Sustainable Energy
Homework 11
Due: 1pm, Tues Dec 5, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Short report **{20 points}**

Write a short critical summary (about 300 words) of a recent published article which is related to the topics covered in recent lectures, namely alternate energy and energy storage. You can choose the article but first read the instructions for writing the report which are on the course web page in the “Materials” tab.

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

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. Watch the “Importance of Energy Storage” video on the course website. According to the video, underground caverns are already being used to store
 - (A) natural gas
 - (B) old wind turbine blades
 - (C) electrolyte solutions
 - (D) chlorofluorocarbons
2. Watch the “Importance of Energy Storage” video on the course website. In the video, which of the following is *not* mentioned as an advantage of flow batteries over lithium-ion batteries?
 - (A) flow batteries can be cheaply scaled to larger sizes
 - (B) flow batteries operate at higher voltages
 - (C) flow batteries don’t lose their charge so quickly (“capacity fade”)
 - (D) flow batteries are less likely to burst into flames
3. To raise one kilogram of mass by a vertical distance of 1 meter requires 10 Joules of energy. How much energy is stored in a hydroelectric power system where the reservoir holds 50,000 tons of water positioned on a hilltop 200 m above the turbines that are used to generate electricity?
 - (A) 100 kWh
 - (B) 100 MWh
 - (C) 30 kWh
 - (D) 30 MWh
4. Respiration is
 - (A) the conversion of cellulose to a fuel
 - (B) the conversion of plant materials to coal, oil, or natural gas
 - (C) a process by which sugars are fermented to a liquid fuel
 - (D) the reverse of photosynthesis

5. A flywheel energy storage plant has a storage capacity of 20 MWh. For how many hours could it power a town of 5000 houses, if each house consumes energy at a rate of about 1kW?
(A) 4 hours (B) 2 hours (C) 1 hour (D) 30 minutes
6. Biofuels can be produced by
(A) extracting oil from oleiferous plants like soy or canola
(B) using acid to dissolve wood into a liquid
(C) adding ethanol to regular gasoline
(D) chemical conversion of coal into a synthetic liquid fuel
7. Advantages of biofuels over fossil fuels include
(A) biofuels have lower levels of radioactivity
(B) usage of biofuels does not increase atmospheric GHG levels
(C) fossil fuels do not derive from living material
(D) biofuels produce more energy per gram of fuel
8. Which of the following is an advantage of cellulosic ethanol (“CE”) over other biofuels?
(A) We already know how to produce CE cheaply
(B) CE plants can also be used for food
(C) CE production does not require fertilizers or weedkillers
(D) Cellulose is easily synthesized from coal or oil
9. In terms of GHG emitted per passenger per mile traveled,
(A) conventional cars are better (lower emission) than aircraft
(B) conventional cars are better than light rail
(C) large aircraft are worse than small aircraft
(D) a full (“peak”) bus is better than light rail
10. Carbon “Cap and Trade” means that if a country emits less CO₂ than its allowed maximum then
(A) it will suffer trade sanctions
(B) it earns carbon credits that can be sold
(C) it will have its cap increased
(D) it has to buy carbon credits

Physics 173, Physics of Sustainable Energy
Homework 12
Due: 1pm, Tues Dec 12th, 2023

Please upload your answers at the Canvas website as a PDF file. You can easily convert JPEG photos to PDF using online tools. When doing so, please ensure that in the PDF your photos are in the proper orientation.

Regular questions

When you write out your response, please circle or underline the final answer to each part of the question. This will make it clearly visible to the grader. Remember to give justification for all your answers, and whenever the answer is a number always show the units, e.g. “200 J”, “0.5 kg”.

1. Please supply your evaluation of the course at `evals.wustl.edu`. **{4 points}**
2. Appraisal of nuclear power as an energy source.
 - (a) Describe two important advantages of using nuclear reactors to generate electricity, compared to using solar power.
 - (b) Describe two important disadvantages of using nuclear reactors to generate electricity, compared to using solar power.
 - (c) Roughly how much Uranium-235 (in kilograms) would be consumed to provide one year's supply of electrical energy for a city of about a million houses?

{6 points}

Multiple choice questions

{2 points each}

Each question has one correct answer, unless the question specifies otherwise. You do not have to show your working, but it may help the grader. You may look up online any quantities that are needed but not supplied in the question or in lecture materials. If you hand-write your answers please use capital letters.

1. When an atom of ^{19}O undergoes beta decay what does it turn in to?
(A) a different isotope of oxygen (B) nitrogen (C) fluorine (D) sulfur
2. Which of the following is *not* part of the electromagnetic spectrum?
(A) radio waves (B) microwaves (C) beta rays (D) gamma rays
3. Fission fragments are
(A) uranium nuclei that do not undergo fission
(B) nuclei of atomic mass around 100 that are produced by fission of a larger nucleus
(C) nuclei of atomic mass 238 or larger that were created by fusion in supernovas
(D) neutrons that are produced in a fission process

4. When a ^{235}U undergoes fission, estimate how fast the resultant fission fragments are traveling.
(A) 10^{14} m/s (B) 100,000 m/s (C) 1000 m/s (D) 10 million m/s
5. The definition of “fissile” is: any material in which
(A) the nuclei undergo spontaneous fission
(B) energy can be produced by both fission and fusion of the nuclei
(C) a self-sustaining chain of fission events can occur
(D) neutrons are slowed down by collisions with nuclei
6. The role of the moderator in a nuclear reactor is
(A) to absorb neutrons, which decreases the fission rate
(B) to slow down the neutrons, which increases the fission rate
(C) to emit neutrons, which increases the fission rate
(D) to slow down the neutrons, which decreases the fission rate
7. A conventional nuclear reactor cannot explode like a nuclear weapon because
(A) the total amount of uranium in a reactor is much smaller than in a weapon
(B) the reactor does not contain fissile material
(C) when it gets very hot the chain reaction slows down
(D) the accumulation of fission fragments suppresses further fission
8. The no-threshold linear hypothesis is
(A) mainly used for predicting acute radiation sickness
(B) widely used even though it may have large errors
(C) reliable to within 30% for doses below 0.1 Sv
(D) not applicable to doses of gamma radiation
9. After the Fukushima meltdown, residents of Tokyo (pop. 10 million) each received an average extra radiation dose of 0.004 mSv. According to the linear hypothesis, how many extra cancers were caused by this?
(A) 1 or 2 (B) about 1500 (C) about 40,000 (D) about 200
10. The city of Ramsar in Iran has a high level of background radiation, around 100 mSv/year. According to the linear hypothesis, what would be the resultant increase in the lifetime cancer risk for inhabitants of Ramsar?
(A) +2% (B) less than 1% (C) +30% (D) +10%