

February, 2020

SCIENCE OLYMPIAD AT THE UNIVERSITY OF PENNSYLVANIA



TRIAL: Solar Power C

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Directions:

1. This test is separable. Only marks within the designated boxes will be scored.
2. Work is not required; however, incorrect solutions are eligible for partial credit.
3. Full credit necessitates correct significant figures and units.
4. Each team will have 10 minutes to complete the practical section. Proctors will invite competitors at designated times. Replacement parts will not be given.

Team Number: _____

Team Name: _____

Team Members: _____

Score: _____
Rank: _____

Good Luck!

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Multiple Choice: Select the best answer for the following questions:⁴ (2 points each)

1. Which law of thermodynamics states the following: Two systems are in thermal equilibrium with each other if they are in thermal equilibrium with a third system?
 - (a) Zeroeth
 - (b) First
 - (c) Second
 - (d) Third
2. Which law of thermodynamics states the following: The entropy of a system approaches a value that is constant as the temperature approaches absolute zero.
 - (a) Zeroeth
 - (b) First
 - (c) Second
 - (d) Third
3. Which of the following statements about heat transfer is correct?
 - (a) When heat is transferred from one object to another, the internal energies of the objects changes.
 - (b) Cyclically operating engines have three thermal reservoirs.
 - (c) There is no transport of internal energy in convection.
 - (d) Heat and work are not interconvertible.
4. What form of heat transfer involves that transport of a fluid from one location to another?
 - (a) Radiation
 - (b) Advection
 - (c) Convection
 - (d) Diffusion
5. What type of condensation occurs in a formation of a fog?
 - (a) Condensation in direct contact with a sub-cooled liquid
 - (b) Homogeneous condensation
 - (c) Film-wise condensation
 - (d) Drop-wise condensation
6. What device causes heat to flow preferentially in one direction?
 - (a) Heat engine
 - (b) Thermoelectric cooler
 - (c) Thermal diode
 - (d) Thermocouple

7. Which of the following statements about thermal insulation is correct?
 - (a) It is measured in $W \cdot m^1 \cdot K^1$
 - (b) Before the critical radius is reached, adding insulation would decrease heat transfer.
 - (c) Thermal insulation in a building increases the carbon footprint of that building.
 - (d) Insulation is temporary, unlike heating and cooling equipment which is more permanent.
8. Which of the following is a benefit of thermal insulation in buildings?
 - (a) It is energy-efficient.
 - (b) It creates a more uniform temperature throughout the building.
 - (c) It has a low recurring expense.
 - (d) All of the above
9. Which of the following statements about temperature is correct?
 - (a) A system is at its coldest when its temperature is in absolute zero.
 - (b) Thermal motion does not have a value of zero when the temperature is absolute zero.
 - (c) Temperature is inversely proportional to average kinetic in an ideal gas.
 - (d) The basic SI unit for temperature is Celsius.
10. What material can have the lowest percentage in energy savings?
 - (a) Cardboard
 - (b) Paper
 - (c) Glass
 - (d) Steel
11. Which of the following statements about sorting in recycling is correct?
 - (a) Plastic bags are not removed from the conveyor belt stage.
 - (b) A spectroscopic scanner is the device used to sort different types of paper and plastic based on absorbed wavelengths.
 - (c) Strong magnets are used to separate non-ferrous metals.
 - (d) Glass is sorted by size.
12. What form of recycling cleans and sorts each material before collection?
 - (a) Curbside collection
 - (b) Buy-back center
 - (c) Distribute recycling
 - (d) Source separation
13. Which of the following can be recycled?
 - (a) Tires
 - (b) Batteries
 - (c) Food
 - (d) All of the above

14. What type of business model in reusing materials involves a financial incentive to return packaging for reuse?
 - (a) Refilling programs
 - (b) Closed-loop programs
 - (c) Package deposit programs
 - (d) Regifting
15. Which of the following is a disadvantage of reusing materials?
 - (a) Increased disposal costs
 - (b) Often more expensive to reuse a product than make another one
 - (c) Reusing materials does not open job opportunities
 - (d) Some items that have been reused are can be hazardous or less energy efficient
16. Which of the following is the best estimate of the global renewable power capacity as of 2018?
 - (a) 100 GW
 - (b) 1250 GW
 - (c) 1850 GW
 - (d) 2400 GW
17. Approximately what percentage of the global renewable power capacity as of 2018 comes from wind power?
 - (a) 8%
 - (b) 17%
 - (c) 25%
 - (d) 37%
18. Which country has the largest Solar Photovoltaic capacity as of 2018?
 - (a) China
 - (b) Japan
 - (c) United States
 - (d) India
19. Which country had the largest increase in Solar Photovoltaic capacity between 2017 and 2018?
 - (a) China
 - (b) Japan
 - (c) United States
 - (d) India
20. Which of the following wind turbine configurations are most popular among commercial wind turbines?
 - (a) 3 blades; 3-8 rpm
 - (b) 3 blades; 10-22 rpm
 - (c) 4 blades; 3-8 rpm
 - (d) 4 blades; 10-22 rpm

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21. Which of the following countries is the largest hydroelectric producer?
- (a) Brazil
 - (b) United States
 - (c) India
 - (d) China
22. Which of the following concerns about hydroelectric dams lead to the halt of construction in Europe and North America?
- (a) Cost
 - (b) Environmental concerns
 - (c) Lack of construction materials
 - (d) Inefficiency
23. Which of the following provides the most commercially-important means of large scale grid energy storage?
- (a) Nuclear
 - (b) Pumped Hydroelectric
 - (c) Wind
 - (d) None of the Above
24. Which of the following is NOT a passive solar technique?
- (a) Using solar collectors for heating
 - (b) Orienting a building to the sun
 - (c) Designing spaces that naturally circulate air
 - (d) Selecting materials with favorable light dispensing properties
25. Which of the following is an advantage of Onshore Wind Turbines over Offshore Wind Turbines?
- (a) Less affected to wind turbulence
 - (b) Low wind shear
 - (c) Noise pollution isn't a concern
 - (d) Easily integrated with electrical-grid network

True (T) or False (F): Determine if the following statements are true or false.⁴ (1 pt each)

1. PV is a form of passive solar power.
2. Vertical Axis Wind Turbines (VAWTs) are more efficient than Horizontal Axis Wind Turbines (HAWTs).
3. An advantage of HAWTs is that they are self-starting.
4. Nuclear power is a renewable resource.
5. Wind turbine blades have been known to frequently kill birds.
6. Renewable energy is predicted to equal coal and natural gas electricity generation by 2040.
7. 90% of the global total in solar water heating is in China.
8. PV cells convert the sun's energy into chemical energy, and then into electric energy.
9. The worldwide installed capacity of wind power is 564 GW in 2018.
10. Small hydro systems usually produce up to 50 MW of power.
11. The global installed solar capacity in 2017 was 390 GW.
12. PV systems convert light into electrical AC.
13. The source of geothermal energy is the radioactive decay of minerals and from the formation of Earth.
14. Biomass can only be used directly by the process of combustion.
15. Wood is the second largest biomass energy source.

Short Answer: Write the term that best matches the definition.⁴ (2 points each)

1. What law states that "energy cannot be created nor destroyed"?

2. What law states that the "rate of heat loss of a body is proportional to the difference in temperature between the body and its surroundings"?

3. What type of system can gain or lose energy in associated with matter transfer?

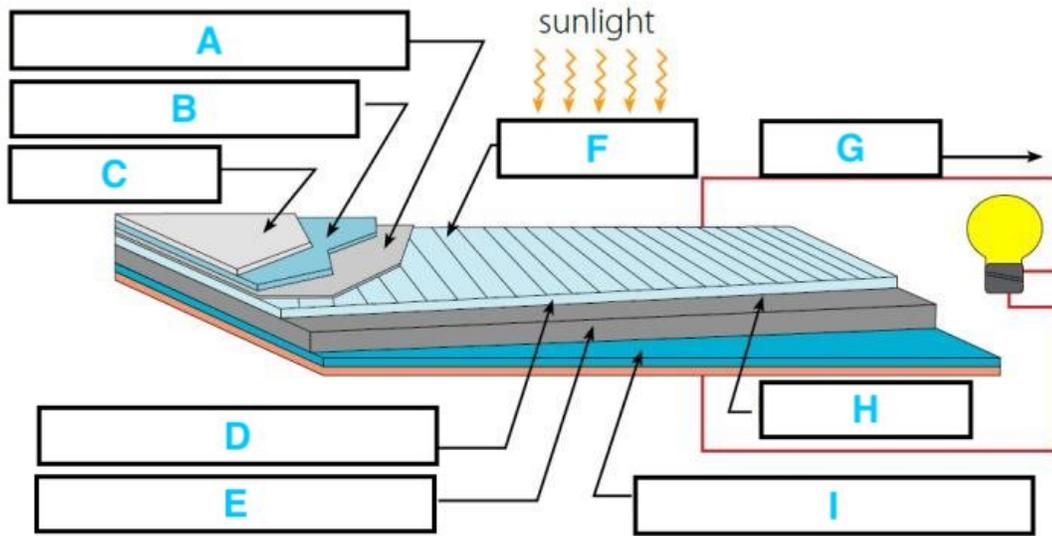
4. What is the term for energy is needed to create a system?

5. What renewable energy technology uses the temperature difference between cooler deep and warmer surface waters?

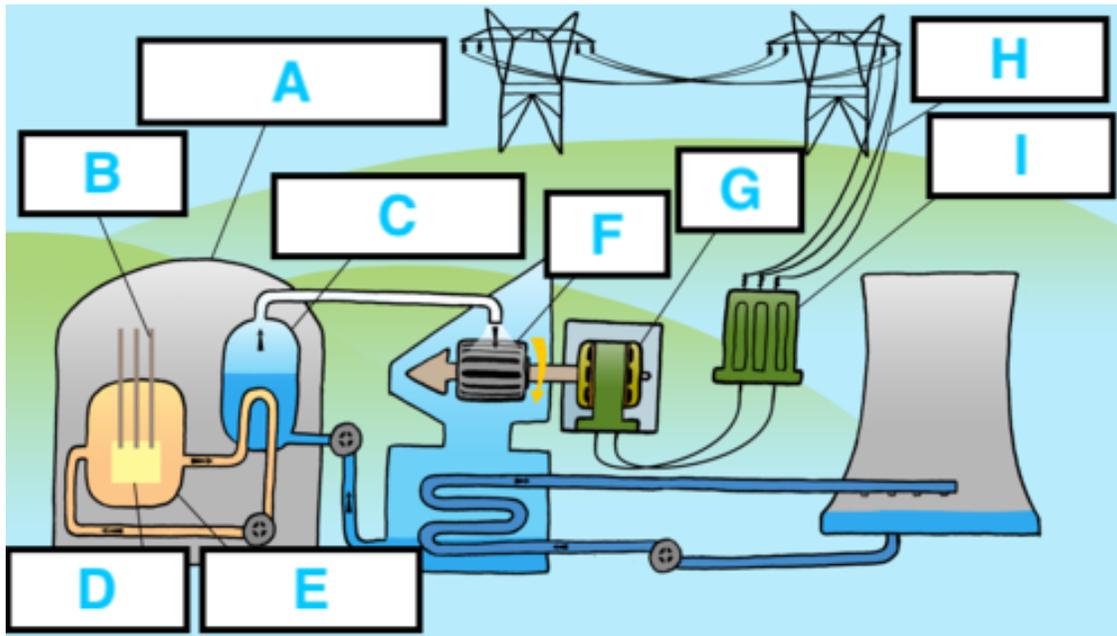
Fill in the Blank: Fill in the statements below with the best answer.⁴ (2 points each)

1. _____ is the amount of energy in transit due to a displacement in the direction of an applied force.
2. A _____ is a device that is capable of converting energy from one form to another (e.g. chemical energy to electrical energy).
3. _____ is a quantity that is equal to the ratio of heat that is added to an object that results in a change in temperature.
4. The _____ is the product of Grashof and Prandtl numbers.
5. _____ is the only country running on 100% renewable energy.
6. The _____ is the “poster child” of marine energy because it has the highest tidal flow on Earth.
7. _____ is the most abundant fossil fuel on Earth.
8. _____ is the country leading in solar thermal power deployment.
9. _____ ethanol fuel program has existed since the 1970s.
10. The _____ is the second highest producer of geothermal power in the world.

Labeling: Complete the diagrams below. ⁴ Each letter is worth one point.

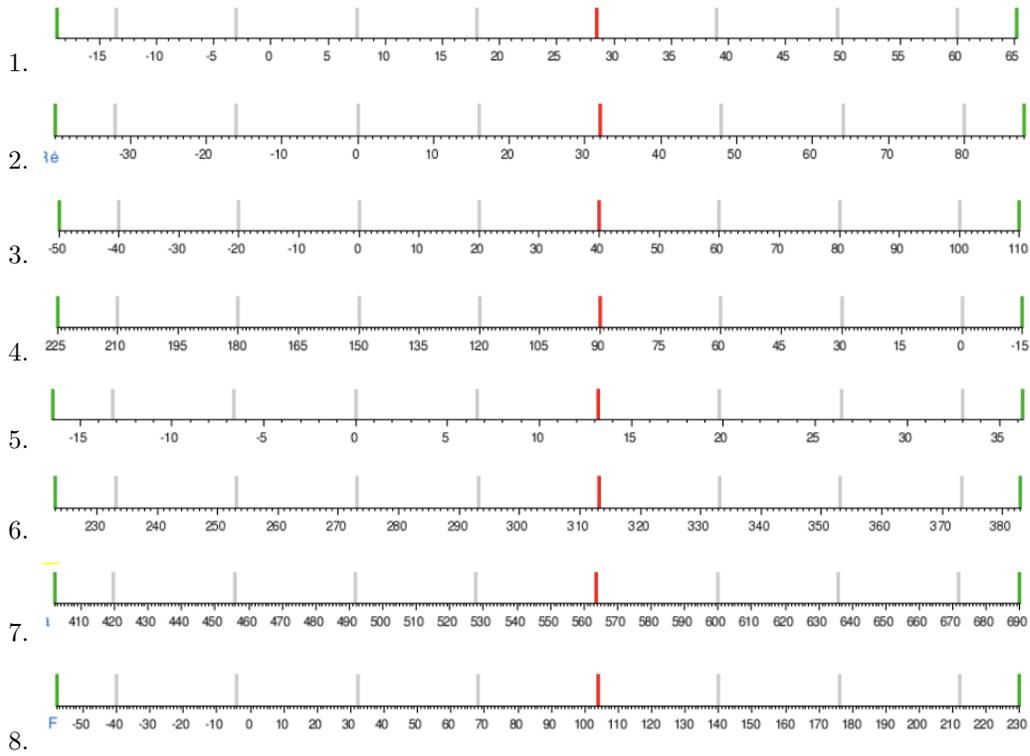


1.



2.

Temperature Scales: Match each scale with the corresponding answer choice.⁴ One point each.



Answer Choices:

1. Reaumur
2. Rankine
3. Newton
4. Deslisle
5. Romer
6. Fahrenheit
7. Kelvin
8. Celsius

Mathematical Equations:⁴

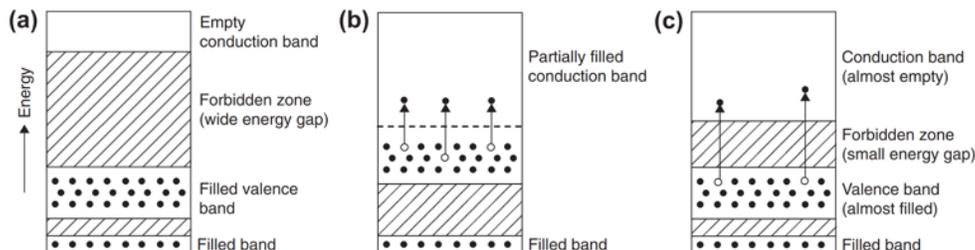
1. Write a line integral for work as a function of force. (2 points).
2. Answer the following questions about the equation given below:

$$\eta_{max} = \eta_{Carnot} = 1 - \frac{T_C}{T_H}$$

- (a) This formula is used for what theorem? (1 pt)
 - (b) Based on modern thermodynamics, the theorem in part (a) is a result of which law of thermodynamics? (1 pt)
 - (c) What does T_c represent? (1 pt)
 - (d) What does T_h represent? (1 pt)
 - (e) Would fuel cells and batteries be limited by the theorem in part (a)? Explain. (3 pts)
3. Write down the Stefan-Boltzmann equation for an object in a vacuum. (2 pts)
 4. What is the equation for Celsius as a function of Kelvin? (2 pts)

Material Properties by Aditya: Modern photovoltaics research often includes investigating material properties of semiconductors, the chemical building blocks of modern electronic devices. Over the next few questions, we'll examine a small portion of the materials science behind semiconductors, after which we'll look at a promising area of research for solar power: singlet fission.³

1. Consider three materials (A, B, and C), which have the following band structures (denoted as a, b, and c, respectively):



- (a) Order the materials with regard to their conductivity, from most conductive to least conductive. (3 pts.)
- (b) Determine which material, if any, would be best suited for the design of a photovoltaic cell. (2 pts.)
- (c) In an experiment, a researcher increases the temperature of material C. How will this increase in temperature affect the material's resistivity? (2 pts.)
- (d) Suppose that the primary component of material A is replaced with an element that has a larger electronegativity than before. How will this change affect the band gap of material A? (2 pts.)
2. While conducting an experiment, a researcher discovers that a newly-synthesized material exhibits an "optical band edge" at a frequency of 4.3×10^{14} Hz (i.e., it stops absorbing light at this frequency).
- (a) At which wavelength of light, in nanometers, does the optical band edge occur? (2 pts.)
- (b) Sketch a graph of absorbance vs. wavelength for this material. Assume that the material either perfectly absorbs or transmits light, depending on the wavelength. (8 pts.)

- (c) What color would you expect this material to appear when placed under white light? (2 pts.)
- (d) Estimate the band gap of this material, in eV. (4 pts.)
3. In 1961, William Shockley and Hans-Joachim Queisser postulated that the maximum theoretical efficiency of a solar cell was only about 30%, given some assumptions. One of their assumptions was that each incoming photon only creates one exciton (an electron and electron-hole pair). Singlet fission operates on the idea that a high-energy exciton (singlet) can be split into multiple, lower energy excitons (usually two triplet excitations), allowing the average number of excitons transferred into the solar cell per photon to exceed one.
- (a) First, let's consider a typical, silicon photovoltaic cell like those commercially available today. What happens when high-energy photons hit this type of cell? How does it contribute to the cell's inefficiency? (6 pts.)
- (b) Since energy is conserved, when a singlet exciton splits into two triplet excitons, the combined energies of the triplets must be less than or equal to the original energy of the singlet. As a result, a student is skeptical that singlet fission improves the efficiency of the cell. Imagine you're a professor – how would you explain this concept to the student? Feel free to be creative! (10 pts.)

- (b) Calculate the total amount of energy to perform steps 1-5. (6 pts)
3. Bromine melts at 7.25 C and boils at 58.8 C. The enthalpy of fusion of bromine is 10.57 kJ/mol and the enthalpy of vaporization of bromine is 29.96 kJ/mol. The specific heat of liquid bromine is 0.474 J/gK. How much heat, in kJ, is required to convert 31.5 g of solid bromine at 13.2 C to the gas phase at 58.8 C? (6 pts)
4. Define the geothermal gradient and describe its role in the Earth's heat transfer. (3 pt)