MAE 119 W2018 FINAL EXAM
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Part I: MULTIPLE CHOICE SECTION – 2 POINTS EACH

1. Which best describes the working definition of energy used in class:
    a. Energy can be transformed and in doing so can be used to perform work.
    b. Energy is gradually consumed in proportion to the amount of work performed.
    c. Energy is the time rate of change of power.
    d. None of the above.
2. Which phrase best captures the first law of thermodynamics?
    a. Energy cannot be stored effectively as it gradually is lost from a system.
    b. Power is given by the time-rate-of-change of energy
    c. Energy can be converted from one form to another but is always conserved
    d. The degree of disorder in a system gradually increases.
3. Primary forms of energy include:
    a. Petroleum, Natural Gas, Fissile Material
    b. Coal, Gas, and Refined petroleum products
    c. Electricity
    d. All the above
4. Which of these are common energy end uses:
    a. Electricity Generation
    b. Transportation fuels
    c. Heating
    d. All the above
5. Adequate access to energy services is linked to
    a. Energy Intensity
    b. Human quality of life
    c. Increased population growth rate
    d. Reduced carbon intensity
6. The Kaya Identity is used to connect carbon emission rates to which of the following?
    a. Human population
    b. Energy and Carbon Intensity
    c. Per-capita economic activity
    d. All the above.
7. About how long does CO_2 emitted from fossil fuel combustion reside in the Earth's atmosphere?
    a. 10 years
    b. About one human generation
    c. Several 100s of years.
    d. It stays forever.
8. Which of the following strongly absorb infra-red radiation in the Earth's atmosphere?
    a. Nitrogen and Oxygen
    b. Water Vapor
    c. Methane and Carbon Dioxide
    d. Both B and C
    e. A, B and C are all strong IR absorbers.

9. If all forms of energy use are included, the rate of energy consumption by human beings today is about
    a. 100 million barrels of oil/day
    b. 15 TW
    c. About 10x the rate of today's renewable energy production
    d. None of the above.
10. The capacity factor of an electrical power generation technique is defined as
    a. The relative fraction of the electrical power demand that it can provide
    b. It is another phrase used to describe the efficiency
    c. It tells how often the technology is available for use
    d. It is the ratio of the average power produced divided by the system's peak rated power.
11. The maximum theoretical efficiency of a wind turbine is
    a. about 60%
    b. depends on the details of the turbine design
    c. can approach 100% if the wind blows all the time
    d. none of the above
12. What considerations impact how much wind power can be extracted from a large array of wind turbines?
    a. Interactions between the turbines in the array limit how close they can be spaced
    b. The turbine array will slow down the wind in the lower region of the boundary layer
    c. The average wind speed and the variation of the wind speed matter
    d. All the above
13. The intermittency of renewable energy resources can be reduced by
    a. Using solar PV, wind and/or solar thermal sources spread out of a large geographic area
    b. Using backup conventional fossil fueled systems
    c. Using pumped hydro or batteries to store excess energy
    d. All the above
14. Which of these resources can be expected to meet a significant fraction of human energy demand for the foreseeable future?
    a. Wind, nuclear fission, fossil fuels
    b. Wave, tidal, ocean thermal and ocean currents
    c. Conventional geothermal power
    d. None of the above.
15. The efficiency of a solar cell can be increased by
    a. Increasing the band-gap energy of the material
    b. Increasing the minority charge carrier lifetime in the material
    c. Reducing the rate of minority carrier losses due to defects
    d. Both B and C are correct.
    e. A, B and C are all correct.

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Part II: ONE SHEET OF NOTES AND CALCULATORS ARE PERMITTED. NO OTHER ELECTRONIC DEVICES ARE PERMITTED. 15 points each.

1. Light from a star shines on a planet with intensity I, and all of it is absorbed on the surface. The surface then heats up to a temperature T>0.
   a. If there is no atmosphere, find an expression for the surface temperature. 10 points.
   b. Suppose there is now an atmosphere that is perfectly transparent to the solar radiation, and perfectly absorbing to the radiation emitted from the planet's surface. The atmosphere warms up as well, and radiates 50% of its heat towards the planet's surface, and half to space. What is the new surface temperature? 10 points.

2. Suppose human beings instantaneously inject a mass, M, of CO_2 into the Earth's atmosphere at time t=0. Using our carbon balance model developed in class, how does the transient in the mass of CO_2 in the atmosphere respond for t>0? 20 points.

3. A solar thermal power plant collects solar radiation with a DNI of 1000 W/m^2 and concentrates this by a factor of 1000 onto the hot target of the plant.
   a. Coolant circulating through the target removes 50% of this heat flux and delivers it to a heat engine. What is the resulting target temperature if convective heat losses to the atmosphere can be neglected? 10 points.
   b. If the coolant achieves a temperature that is 50% of the target temperature, and the cold reservoir has a temperature of 400 K, how much power can an ideal heat engine produce per unit target area? 10 points.
   c. A cloud layer that is 1km thick containing small particles with a cross-sectional area of 10^{-8} cm^2 and a density of 1000 particles/cm^3 and larger particles with a cross-sectional area of 10^{-9} cm^2 at a density of 10,000 particles/cm^3. By how much does the DNI change? 10 points.

4. A solar PV cell exposed to 1kW/m^2 of solar radiation has a short-circuit current of 30mA/cm^2 and an open circuit voltage of 1 V.
   a. Draw the I-V characteristic for this device, labeling the short circuit current, open circuit voltage, and point of maximum power operation. 10 points.
   b. If the Form Factor for this cell is 0.66, what is the cell's efficiency? 5 points.
   c. Suppose you double the minority carrier lifetime in the cell. What happens to the I-V curve and the efficiency? 5 points.
   d. Name two ways you could increase the carrier lifetime of the cell. 5 points.

5. A wind turbine is placed at a site where the wind has a equal probability of having a speed anywhere between 0 and 10 m/sec. The turbine is designed to produce maximum power for a wind speed of 10 m/sec, and the wind never blows at a speed above 10 m/sec.
   a. What is the average wind speed, V_{ave} ? 5 points.
   b. What is the corresponding average wind power density (W/m^2)? 10 points.

c. Compare your answer to part a and part b. Why isn't the answer to part b equal to $\frac{1}{2}\rho V_{ave}^3$?

10 points.

d. What is the capacity factor of a turbine placed at such a site? 5 points.

6. Suppose that two species of greenhouse gases are injected into the atmosphere and are uniformly mixed such that there are n_1 molecules/volume for species 1 and n_2 molecules/volume for species 2. The infra-red radiation absorption cross-section for the two species is given as s_1 and s_2.

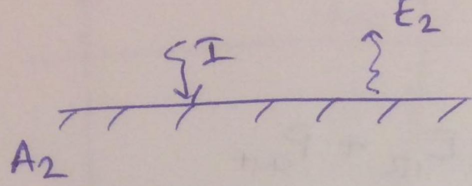
a. *Derive* an ordinary differential equation governing the variation of unabsorbed IR radiation with position in this atmosphere. 10 points.

b. Solve the equation from part a to find the transmission coefficient through an atmosphere of thickness d? 10 points.

MAE 119 / W 2018 / Final Solutions

1) a
2) c
3) b
4) d
5) b
6) d
7) c
8) d
9) b
10) d
11) a
12) d
13) d
14) a
15) d

1) a) $\wr_{\downarrow} I$



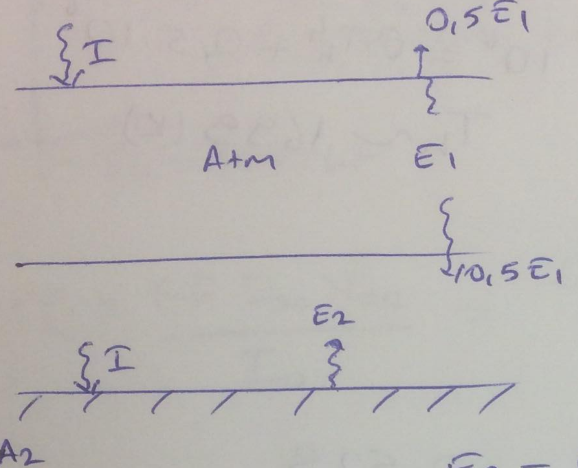
$$A_2 = I$$

$$E_2 = A_2 = I$$

$$E_2 = \sigma T_s^4$$

$$T_s = \sqrt[4]{\frac{I}{\sigma}}$$

b)



$$A_2 = I$$

$$E_1 = E_2$$

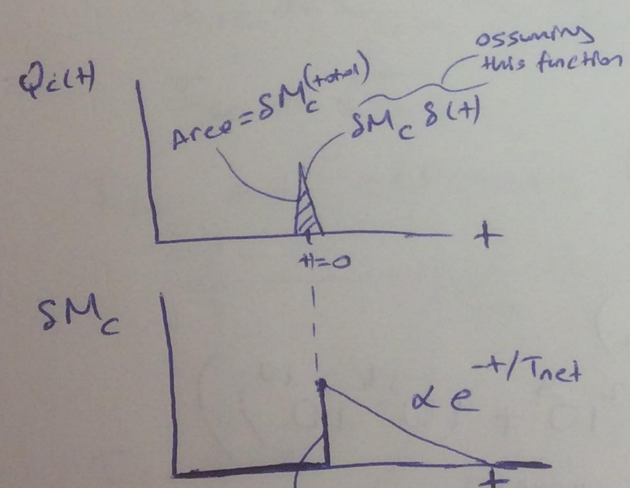
$$E_2 = I + 0{,}5\,E_1$$

$$I = 0{,}5\,E_1$$

$$E_2 = \sigma T_s^4$$

$$T_s = \sqrt[4]{\frac{E_2}{\sigma}} = \sqrt[4]{\frac{I + 0{,}5 E_1}{\sigma}}$$

2)



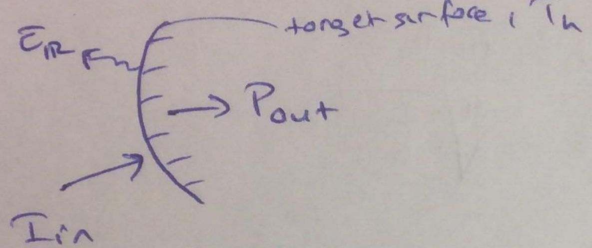
$$\text{Jump} = \int_{t=-\epsilon}^{+\epsilon} Q_c(t)\,dt$$

3)

a) $I_{in} = I_o C$

$= 1000 \cdot 1000$

$= 10^6 (W/m^2)$



$I_{in} = E_{IR} + P_{out}$

$I_o C = \sigma T_h^4 + P_{out}$

$10^6 = \sigma T_h^4 + 0{,}5 \cdot 10^6$

$T_h \sim 1693 \, (K)$

b) $T_{coolant} \sim 849{,}5 \, (K)$

$T_{cold\ reservoir} = 400 \, (K)$

$\eta = 1 - \frac{T_c}{T_h} = 1 - \frac{400}{849{,}5} = 0{,}529$

$P = 0{,}5 \, 10^6 \, 0{,}529$

$= 264500 \, (W/m^2)$

c) $I(x) = I_o \exp\left(\frac{-x}{L_{scatt}}\right)$

$L_{scatt} = (n_p \sigma_{scatt})^{-1}$

$I(x) = I_o \exp(-x \, n_p \, \sigma_{scatt})$

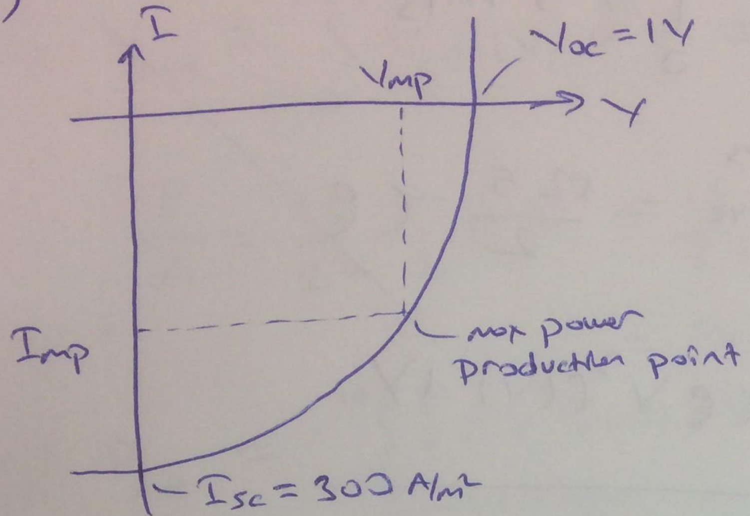
$I(x) = I_o \exp\left(-\underset{(m)}{10^3}\left(\underset{(m^2)}{10^{-12}} \underset{\left(\frac{\#particles}{m^3}\right)}{10^9} + 10^{-13} \, 10^{10}\right)\right)$

$= I_o \exp(-2) = I_o \cdot 0{,}135$

DNI is reduced by 86,5 %

4)

a)



$$FF = \frac{I_{mp} V_{mp}}{I_{sc} V_{oc}}$$

b) $\eta = \frac{FF\, I_{sc} V_{oc}}{I_o} = \frac{0{,}66 \cdot 300 \cdot 1}{1000} = 0{,}18$

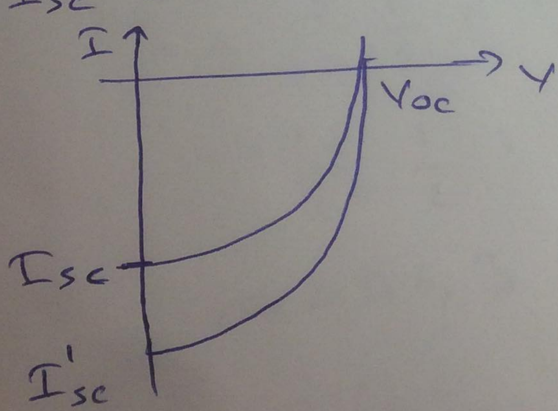
18 % Efficiency

c) V_{oc} doesn't change

$I_{sc} \propto L_{e,h} \propto \tau_{e,h}^{1/2}$ $\quad L = \sqrt{D\tau}$

$I_{sc} \propto \sqrt{2}$,

I_{sc} and efficiency increase by $\sqrt{2}$ times.



d) Carrier lifetime of the cell could be increased by decreasing the number of impurities and grain boundary density.

5)

a) $V_{ave} = \int_0^{10} V f(V)\, dV = 0.1 \frac{V^2}{2} \Big|_0^{10} = 5 \, m/s$

$\frac{P}{A} = \frac{16}{27} \frac{1}{2} \rho V^3 = \frac{16}{27} \cdot \frac{1}{2} \cdot 1 \cdot 125$

$= 37 \; (W/m^2)$

b) $\frac{P_{ave}}{A} = \frac{\int_0^{10} \frac{1}{2} \rho V^3 f(V)\, dV}{\int_0^{10} f(V)\, dV} = \frac{1}{2} \rho \, 0.1 \frac{V^4}{4} \Big|_0^{10}$

$= \frac{1}{2} \, 1 \, 0.1 \frac{10^4}{4}$

$= 125 \; (W/m^2)$

c) $\frac{P_{ave}}{A} > \frac{P_{(V=5m/s)}}{A}$ since $P \propto V^3$, large speeds weights more

d) $\frac{P_{max}}{A} = \frac{16}{27} \frac{1}{2} \rho V_{max}^3$

$= \frac{16}{27} \frac{1}{2} \, 1 \, 10^3$

$\simeq 296{,}3 \; (W/m^2)$

$P_{ave} = C_F P_{max}$

$C_F = \frac{125}{296{,}3} \simeq 0{,}422$

$\sim 42{,}2 \%$

6)

a) From a depth of x to $x+dx$, the change in IR radiation intensity $dI(x)$

$$dI(x) = -(n_1 S_1 + n_2 S_2) I(x)\, dx$$

$$\frac{dI(x)}{I(x)} = -(n_1 S_1 + n_2 S_2)\, dx$$

b) $$\int_{I(0)}^{I(d)} \frac{dI}{I(x)} = -\int_0^d (n_1 S_1 + n_2 S_2)\, dx$$

$$\ln I(x) \Big|_0^d = -(n_1 S_1 + n_2 S_2)\, d$$

$$\ln \frac{I(d)}{I(0)} = -(n_1 S_1 + n_2 S_2)\, d$$

$$\beta = \frac{I(d)}{I(0)} = \exp\left(-(n_1 S_1 + n_2 S_2)\, d\right)$$