The Norwegian University of Science and Technology
Department of Physics

ENGLISH

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EXAM IN TFY 4300 Energy and environmental physics

Monday August 3rd 2009
Duration: 4 hours

Number of pages: 5

Permitted aids: 1) Calculator HP30S or Citizen SR-270X
2) English Dictionary: "The Pocket Oxford English Dictionary" or "The Mini Oxford English Dictionary"

No other dictionary or calculator is allowed.

Mobile phones must be shut off and shall not appear on the desk during the exam.

If you need to ask clarifying questions, please contact the exam inspector and he/she will put up a phone call for you to the contact person listed on the top of page 1.

You shall hand in the white pages, the yellow pages you keep for reference. Do not write in the margin to the left, this space is reserved for the censoring.

In the upper right corner the following must be written: Your NTNU student number, date, page no (*side*), and total number of pages (*Antall ark*). Also the Subject Code (*Fagnr/emnekode*) as given on the problem set must be written. Do NOT write your name anywhere in the papers.

Physical parameters and lists of equations are given in the appendix.

You have to answer all questions in all 3 problems. The weight for each problem is given in the parenthesizes.

Problem 1. The Greenhouse effect, the carbon cycle and fossil fuels (25%)

a) (5%) What is the natural greenhouse effect? What gasses contribute the most to the natural greenhouse effect? What would the temperature on the surface of the Earth be if there was no atmosphere?

b) (5%) Make a schematic drawing of the global carbon cycle. Include the atmosphere, land, fossil fuels, surface layers of the oceans and deep oceans. Indicate in the drawing the <u>order of magnitudes</u> of carbon content in the various parts of the system. Indicate also in what parts of the system the carbon content is increasing and where it is decreasing.

c) (15%) Describe how fossil fuels are utilized today and explain briefly what the problems related to fossil fuels are. If we use the (global) known reserves of fossil fuels at the same rate as today, how long will they last, approximately?

Problem 2. Nuclear fusion (25%)

a) (5%) Describe what happens in a nuclear fusion process and how this process can be utilized to generate electricity.

b) (5%) How much energy is typically released in a fusion process, and how does it compare to the amount released in nuclear fission and in combustion of fossil fuels?

c) (5%) Give examples of possible nuclear fusion processes. Which is the one mostly looked into for electricity generation?

d) (5%) What are the challenges in utilizing nuclear fusion for electricity generation?

e) (5%) Give one example of a fusion reactor that has been tried out. What fuel is needed and where the fuel is taken from?

Problem 3. Electricity supply (50%)

a) <u>Wind turbine power (15%)</u>
Give an expression for the power generated by a wind turbine in a wind of speed u_o and air density ρ, intercepting a cross-section A of the wind front. What does the power coefficient C_P tell us? What is the maximal value of C_P? Why is it not 100%? (i.e. Why can we not extract 100% of the energy in the wind?)

The electricity consumption in Norway is ca 110TWh per year. How many windmills with a diameter of 80m are needed to supply 25% (i.e 27.5TWh) of this consumption by wind energy? (1TWh = 10^{12}Wh)

Assume that the average wind speed is 8m/s, an air density of 1.2kgm^{-3}, that the efficiency of the windmill is 50% of the maximum theoretical value, and a generator efficiency of 95%.

b) <u>Electricity from solar cells (15%)</u>
How does a solar cell work? What are the advantages or disadvantages over wind power?

How large area of Norway need to be covered with solar cells to generate 27.5TWh electric energy in one year, if the annual solar irradiation is 900kWh/m^2 and the solar cell has a typical efficiency. (If you don't remember the typical efficiency assume that it is 20%).

c) <u>Electricity from biomass (15%)</u>
What is energy farming? What are the advantages and problems related to energy farming?

Assume that the forests in Norway can supply 100 GJha^{-1} per year, how many km^2 is then needed to generate 27.5TWh electric energy per year in a steam turbine power plant fuelled with timber from the forests? Assume a steam turbine power plant efficiency of 36% (including the generator efficiency). 1 ha = 10^4 m^2.

d) <u>Coal fired power plants (5%)</u>
What is the typical efficiency of a coal fired power plant? If the same amount of electricity (27.5TWh/year) should be provided by a typical coal fuelled power plant, approximately how much thermal energy should the coal provide (in TWh per year)? (Use 40% for the efficiency if you don't know what it typically is.)

What are the advantages for coal fired power plants compared to wind power, solar cells and bioenergy?

APPENDIX

1 ha = 10^4 m^2

List of equations

$pV = nRT$ $p = \rho R_{air} T$ $\frac{\partial p}{\partial z} = -\frac{p}{H}$ $\frac{\partial T}{\partial z} = -\frac{g}{c_p} = -\Gamma_d$ $E = h\upsilon$ $I_E dE = \frac{2\pi \nu^3}{c^2} \frac{1}{e^{h\upsilon/kt} - 1} dE$ $I_\lambda = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kt} - 1}$ $\lambda_{\max} T = 2898[\mu m\ K]$ $I(T) = \sigma T^4$ $\Delta T_s = G \Delta I$ $G_f = \frac{G}{1 - \sum_n GH_n}$ $\Delta T_s = G_f \Delta I$ $\Delta T_s(t) = (\Delta T_s)_{ss}(1 - e^{-t/\tau})$ $P_T = IV$	$P_{ij} = \frac{\Delta T}{R_{ij}}$ $q = \frac{P}{A} = \frac{\Delta T}{r}$ $r = \frac{1}{h} = RA$ $r_n = \frac{\Delta x}{k}$ $\quad R_n = \frac{\Delta x}{kA}$ $r_v = \frac{X}{\mathcal{N} k}$ $\quad R_v = \frac{X}{\mathcal{N} kA}$ $r_r = \frac{(T_1 - T_2)}{q}$ $\quad R_r = \frac{(T_1 - T_2)}{P_{12}}$ $P_v = A\mathcal{N} \frac{k(T_s - T_f)}{X}$ $\mathcal{R} = \frac{uX}{\nu}$ $\mathcal{A} = \frac{g\beta X^3 \Delta T}{\kappa \nu}$ $P_m = \frac{dm}{dt} c(T_3 - T_1)$ $P_m = \frac{dm}{dt} \Lambda$ $-mc \frac{d}{dt}(T_1 - T_0) = \frac{(T_1 - T_0)}{R_{10}}$	$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$ $P_r = A\varepsilon\sigma T^4$ $P_{12} = \sigma(T_1^4 - T_2^4) A_1 F_{12}$ $P_{12} = A_1 F_{12}^{'} \sigma(T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2)$ $R_r = \left[A_1 F_{12}^{'} \sigma(T_1^2 + T_2^2)(T_1 + T_2) \right]^{-1}$ $P_{net} = \tau_{\text{cov}} \alpha_p A_p G - \frac{T_p - T_a}{R_L} = \eta_{sp} A_p G$ $P_u = \eta_{pf} P_{net} = \begin{cases} mc \frac{dT_f}{dt} \\ \frac{dm}{dt} c(T_2 - T_1) \end{cases}$ $mc \frac{dT_r}{dt} = \tau\alpha GA + P_{boost} - \frac{(T_r - T_a)}{R}$ $\eta = \frac{W}{Q_H} = 1 - \frac{Q_C}{Q_H}$ $\eta_{Carnot} = 1 - \frac{T_C}{T_H}$ $COP = \frac{Q_C}{W_{in}}$ $B = (U - U_f) + p_o(V - V_f) - T_o(S - S_f)$ $B = Q\left(1 - \frac{T_0}{T_H}\right)$

$$c = 2c_g = \frac{g}{2\pi}T$$

$$E = k_E H^2; \quad k_E = \frac{\rho g}{8}$$

$$J = c_g E$$

$$J = k_J T H^2; \quad k_J = \frac{\rho g^2}{32\pi}$$

$$E = \rho g\, H^2/8$$

$$E = \rho g \int_0^\infty S(f)\,\mathrm{d}f \equiv \rho g\, H_s^{\,2}/16$$

$${}^{235}\mathrm{U} + \mathrm{n} \rightarrow {}^{236}\mathrm{U} \rightarrow X + Y + \upsilon\mathrm{n} + \text{energy}$$

$$\eta = \nu \frac{N(235)\sigma_f(235)}{N(235)\left[\sigma_f(235) + \sigma_c(235)\right] + N(238)\sigma_c(238)}$$

$$\frac{dN}{dt} = \frac{\rho N}{l}$$

$$l^* = (1-\beta)l + \beta t_d$$

$${}^2\mathrm{D} + {}^3\mathrm{T} \longrightarrow {}^4\mathrm{He} + {}^1\mathrm{n} + 17.6\mathrm{MeV}$$

$$P_L = \alpha n^2 \sqrt{kT} + 3n\frac{kT}{\tau_E}$$

$$P_{th} = \langle \sigma u \rangle E \frac{n^2}{4}$$

$$P_T = P_L + P_{th}$$

$$\eta P_T > P_L$$

$$F_g = \frac{G m_1 m_2}{R_{12}} \qquad F_c = mR\omega^2$$

$$\frac{GMM'}{D^2} = ML\omega^2 = M'L'\omega^2$$

$$\frac{\partial^2 z}{\partial t^2} = gh\frac{\partial^2 z}{\partial x^2} = c^2\frac{\partial^2 z}{\partial x^2}; \quad c = \sqrt{gh}$$

$$T_r = \frac{\lambda}{c} = \frac{4L}{jc} = \frac{4L}{j\sqrt{gh}}$$

$$\overline{\mathrm{P}} = \frac{\rho A R^2}{2} g \cdot \frac{1}{\tau} = \frac{\rho A g}{2\tau}R^2 \qquad \overline{\mathrm{P}} \approx \frac{\rho A g}{2\tau}\left(\frac{R_{\max}^{\;\;2} + R_{\min}^{\;\;2}}{2}\right)$$

$$q = \frac{P}{A} = \frac{\rho u^3}{2}$$

$$\overline{q} = \eta \frac{\rho \overline{u^3}}{2} = \eta \frac{\rho}{2} \frac{u_0^3 \int_{t=0}^{t=\tau/4} \sin^3(2\pi t/\tau)dt}{\int_{t=0}^{t=\tau/4} dt} \approx 0.1\,\rho u_0^3$$

$$V_B = \frac{E_g}{e} - \left(\phi_n + \phi_p\right)$$

$$np = C = n_i^{\,2}$$

$$W \approx \sqrt{\frac{2\varepsilon_0 \varepsilon_r V_B}{e\sqrt{np}}}$$

$$I(V) = I_L - I_D = I_L - I_0\left[\exp\left(\frac{eV}{AkT}\right) - 1\right]$$

$$\Delta\mu = E_{Fn} - E_{Fp} = eV$$

$$\eta = \frac{I_\mathrm{m} \cdot V_m}{P_{in}} = FF \cdot \frac{I_{sc} \cdot V_{oc}}{P_{in}}$$

$$FF = \frac{I_\mathrm{m} \cdot V_m}{I_{sc} \cdot V_{oc}}$$

$$\rho = \frac{(n_0 - n_1)^2}{(n_0 + n_1)^2}$$

$$CO_2 + H_2\dot{O} \xrightarrow{light} \dot{O}_2 + \left[CH_2O\right] + H_2O$$

$$P_T = C_P A \frac{\rho u_0^3}{2}$$

$$P_o = A\frac{\rho u_0^3}{2}$$

$$F_A = \frac{\Delta \mathrm{p}}{\Delta t} = \frac{m(u_0 - u_2)}{\Delta t} = \rho A_1 u_1 (u_0 - u_2)$$

$$F_A = A_1(p_{1u} - p_{1d}) = A_1 \rho (u_0^{\;2} - u_2^{\;2})/2$$

$$P = u_1 F_A$$

$$P_T = u_1 F_A = u_1 \frac{dm}{dt}(u_0 - u_2)$$

$$P_T = \frac{1}{2}\frac{dm}{dt}(u_0^{\;2} - u_2^{\;2})$$

$$a = \frac{u_0 - u_1}{u_0}$$

$$P_T = \left[4a(1-a)^2\right]P_0$$

$$C_P \le \frac{16}{27}$$

$$\frac{1}{\left(D \pm r\right)^2} = \frac{1}{D^2}\left(1 \pm \frac{2r}{D}\right)$$