NTNU – Trondheim
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Department of Physics

Examination paper for FY2290: Energy Resources

ENGLISH - pages 1-9

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Examination date: 19-05-2021
Examination time: 09:00 – 13:00
Permitted examination support material: All support material is allowed. English language.

Other information: The exam is in two parts. Part 1 is multiple choice, part 2 is written answers that may contain brief description of each step in calculation. Answer all questions in both parts **as detailed as possible**. The percentage of marks awarded for each question is shown. An Appendix of useful information is provided at the end of the question sheet.

Make your own assumptions: If a question is unclear/vague, make your own assumptions and specify them in your answer. Only contact academic contact in case of errors or insufficiencies in the question set.

Saving: Answers written in Inspera are automatically saved every 15 seconds. If you are working in another program remember to save your answers regularly.

Several questions require uploading of scans of handwritten solutions. All files must be uploaded before the examination time expires. **30 minutes** are added to the examination time to manage the sketches/calculations/files; be aware that that the additional time is **only** meant for digitalization of hand drawings and/or file uploading. (The additional time is included in the remaining examination time shown in the top left-hand corner.)

How to digitize your sketches/calculations
How to create PDF documents
Remove personal information from the file(s) you want to upload

Cheating/Plagiarism: The exam is an individual, independent work. Examination aids are permitted, but make sure you follow any instructions regarding citations. During the exam it is not permitted to communicate with others about the exam questions, or distribute drafts for solutions. Such communication is regarded as cheating. All submitted answers will be subject to plagiarism and cheating control. *Read more about cheating and plagiarism here. https://innsida.ntnu.no/wiki/-/wiki/English/Cheating+on+exams*

Language: English
Number of pages: 9 (including cover)

Checked by:

Irina Sorokina   [signature]   Date 10.05.2021
Signature

Part 1. Multiple Choice Questions (56%).

Answer all questions. There is only one correct answer so you must choose the best answer. Answer A, B, C... (Capital letters). A correct answer gives for each of the problems **4 percentage points (4%)** in total towards the final score. Incorrect answers will be awarded **-1 percentage points (-1%)**, blank (unanswered) questions, or multiple answers to the same question will be awarded **0 points (0%)**.

Only the answer will be marked.

Write the answers for the multiple choice questions on the answer sheet you turn in using a table similar to the following (note that the answers in this table are examples of how you should do it):

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Answer	D	C	A	B	E	A	C	A	E	D	B	A	A	A	C

Good luck!

Problems:

1. Recall the world consumption graph. What is the proportion of fossil fuels in the world consumption?
   - A. 30%
   - B. 87%
   - C. 63%
   - D. 33%

2. What is the part of nuclear energy according to the world consumption graph?
   - A. 2%
   - B. 4%
   - C. 7%
   - D. 9%

3. What is the part of renewables (hydro including) according to the world consumption graph?
   - A. 2%
   - B. 4%
   - C. 7%
   - D. 9%

4. A bicyclist expends energy at the rate of 60 Watt. How many calories of energy will he expend in 5 minutes of driving?

A. 3600
B. 12
C. 4300
D. 7200

5. Only about 20% of the potential energy of gasoline is used in powering an automobile. The remaining energy is lost as a low-quality heat. This is an example of the

A. First Law of Thermodynamics
B. Law of Conservation of Energy
C. First-law efficiency
D. Second Law of Thermodynamics

6. At what temperature does the fusion reaction: $^2D + ^3T \rightarrow ^4He + n +$ Energy begin to occur?

A. 1000 K
B. 10^8 K
C. 10^5 K
D. 5800 K

Fusion of ^2D and ^2T can occur at temperatures on the order of 10^8 K.

7. A small cabin style diesel-fired electrical generation station burns 2×10^3 litres of diesel per day. The conversion efficiency from fuel to mechanical motion is 38%, and the generator operates with an efficiency of 95%. What is the power rating of this plant in MWe?

A. 3
B. 52
C. 0.3
D. 2900

Useful heat of diesel H=36 MJ/l =10 kWh/l => $Q = V \cdot H = 20$ MWh per day, which corresponds to thermal power of P = 833 kW.
After conversion to mechanical motion: $P = 0.3\ MWe$.

8. With an albedo of 0.3 and an atmosphere with a long-wavelength transmission of 0.15 and a short wavelength transmission of 0.85 we have seen that the equilibrium temperature of the Earth is around 287 K. A gas is introduced into the atmosphere that decreases the mean long wavelength transmission of the atmosphere from 0.15 to 0.12. If the mean short wavelength transmission of the atmosphere remains unchanged at 0.85 and the albedo remains at 30%, what is the resulting temperature of the Earth?

A. 287 K
B. 293 K

C. 300 K
D. 289 K

⇨ $\varepsilon\sigma B T_e^4 = (S(1-a)/4)*((1+\tau_S)/(1+\tau_L))$, solve for ε/S:
$\varepsilon/S = (0.7/(4x5.7x10^{-8}x287^4))\ (1.85/1.15) = 7.28x10^{-4} m^2/W$ substitute at a new τ_L
$T_{new} = 289K$

9. How large an area needs to be covered with solar cells to generate 11 TWh of electric energy in one year? Assume that the annual solar irradiation is 900 kWh.m^{-2} and that the solar cell has a typical efficiency of 15%.

A. 42 km^2
B. 81 km^2
C. 102 km^2
E. 1640 km^2

The amount of solar electricity generated by the solar cells can be expressed as: $E_{sc} = E_{sun}\eta_{sc}A_{sc}$, *where* E_{sun} *is the incoming solar energy,* η_{sc} *the solar cell efficiency, typically 15%, and* A_{sc} *is the area of the solar cells that we want to calculate. To generate 11 TWh, the area needed is found by setting* E_{sc} *=11 TWh and solving for Asc:*

A= $E_{sc}/E_{sun}\eta_{sc} = 11x10^{12}\ Wh / 900x10^3 Wh/m^2 \times 0.15 = 8.15 \times 10^7\ m^2 \sim 81\ km^2$

10. About 80% of energy released in nuclear fission reactions generates heat (thermal energy) that is used to produce electricity on a nuclear power plant. What is the nature of this thermal energy?

A. Collision of neutrons released in nuclear fission reactions and the moderator
B. Collisional energy exchange between the nuclear fission products and surrounding matter
C. Absorption of gamma rays by the reactor walls
D. Friction between particles emitted in fission and the moderator

11. The commercial nuclear power reactors are based on nuclear fission reactions induced by:

A. protons,
B. electrons,
C. photons,
D. neutrons.

12. The mechanism of extracting energy from biomass is
    A. fusion,
    B. fission,
    C. combustion (burning),
    D. emission of radiation.

13. Photovoltaic cells converting sunlight to electricity can be built with
    A. fissile materials,
    B. semiconductor materials,
    C. tritium,
    D. helium.

14. A star generates energy by nuclear fusion reaction of H nuclei into helium

$$4p \rightarrow {}^{4}_{2}He + 2e^{+} + 2\nu + 18.3\ MeV.$$

It fuses 6×10^{8} tons of hydrogen per second. What is the total energy in MeV the star produces per second?

A. 3.14×10^{10} MeV per sec
B. 1.65×10^{39} MeV per sec
C. 2.06×10^{-11} MeV per sec
D. 6.02×10^{64} MeV per sec

Solution:
6×10^{8} tons of hydrogen => 6×10^{14} g of hydrogen =>
number of $^{1}H=6\times10^{14}\times 6.02\times10^{23}=3.61\times10^{38}$ atoms =>
$3.61\times10^{38}/4 = 9.03\times10^{37}$ reactions =>
$9.03\times10^{37}\times18.3=1.65\times10^{39}$ MeV per sec

Part 2. Calculations (44%)

Answer all questions. The number in brackets represents the contribution of each sub-question to the total score.

All questions should be answered. NO CREDIT will be given for a correct numerical answer unless the work is shown!

1. [11%] Calculate the power in megawatts during outflow from a tidal power plant that encloses a rectangular area of 1×2.5 km, and which fills to a height of 3.6 m above the outlet. Assume an efficiency of 94%, and an emptying time of 1.5 hour.

Solution:

$$P = \eta \frac{mg\left(\frac{h}{2}\right)}{t}$$

$$= 0.94 \frac{\left(1 \times 10^3 \mathrm{m} \cdot 2.5 \times 10^3 \mathrm{m} \cdot 3.6\mathrm{m} \cdot 1.02 \times 10^3 \frac{\mathrm{kg}}{\mathrm{m}^3}\right) \cdot 9.8 \frac{\mathrm{m}}{\mathrm{s}^2} \cdot \frac{3.6}{2} \mathrm{m}}{5400 \ \mathrm{s}} = 28.2 \ \mathrm{MW}$$

2. [11%] In a submitted patent an inventor claims to have developed a novel heat engine that operates with a not so hot nonpolluting flame at 150C and transfers waste heat to the environment at 20C. His promotional flyer claims that 45% of the fuel energy is converted into useful work. Calculate the maximum efficiency of such an engine and compare it to the claim.

Carnot efficiency of this engine is 31%, which is less than 45% claimed by the inventor.

3. The oceans contain about 1.3×10^{24} cm^3 of water. Deuterium constitutes 0.028% by mass of natural hydrogen.

a [6%] What is the total energy in Joules available from this Deuterium by D-D fusion? Assume 4. 0 MeV per fusion event.

Solution:

a)(1.3×10^{24} cm^3)(1.02g/ cm^3)=1.33×10^{24} g H_2O; ~2/18 of this is hydrogen, and 2.8×10^{-4} of that is Deuterium, so 4.13×10^{19}g D. Atomic number 2 -> each 2 grams contains 6.02×10^{23}atoms. It takes two D for each fusion event. Energy available

(1.24×10^{43}atoms/2(atoms/fusion))(4×10^6eV/fusion)(1.6×10^{-19}J/eV)=3.97×10^{30}J (answers that had correct formulation without numerical values for constants received full credit)

b) [5%] For how many years could fusion reactors with 50% efficiency supply 2.0 million MW?

Solution:

b) Reactor energy input per year = (1/0.5) ($2x10^{12}$J/s) ($3.15x10^{7}$s/year)=$1.26x10^{20}$J (Total available)/(use per year)~$3x10^{10}$ years. The hard parts are extracting the D from the ocean and building the reactors...

4. [11%] The world primary energy consumption in 2017 was approximately 13 000 Mtoe. Assuming that flat panel solar cells at a sunny location in Spain can harvest 8 kWh/m^2/day, what area is required (at that location) to supply the energy needs of the earth?

Solution:

13000Mtoe= 13x 10^9toe/(8.6 $x10^{-5}$toe/kWhr)=$1.5x10^{14}$kWhr/year (8kWhr/day-m^2)*365 = 2920kWhr/m^2 $1.5x10^{14}$kWhr/(2920kWhr/m^2)=**$5.2x10^{10}m^2$**

APPENDIX

Energy conversion factors

	J	kWh	Btu	toe
1 Joule (J)	1	2.78×10^{-7}	9.5×10^{-4}	2.38×10^{-11}
1 kilowatt-hr (kWh)	3.6×10^{6}	1	3413	8.6×10^{-5}
1 calorie (cal)	4.184	1.16×10^{-6}	3.97×10^{-3}	1×10^{-10}
1 British thermal unit (Btu)	1055	2.93×10^{-4}	1	2.5×10^{-8}
1 Electron volt (eV)	1.6×10^{-19}	4.45×10^{-26}	1.52×10^{-22}	3.8×10^{-30}

Storage material	MJ per kilogram	MJ per liter (litre)
Deuterium–tritium	330 000 000	0.14
Uranium-235	83 140 000[3]	1 546 000 000
Hydrogen (compressed at 70 MPa)	123	5.6
Gasoline (petrol) / Diesel	~46	~36
Propane (including LPG)	46.4	26
Fat (animal/vegetable)	37	
Coal	24	
Carbohydrates (including sugars)	17	
Protein	16.8	
Wood	16.2	

Density of water 1.02×10^{3} kg/m^3
density of air ~1.2 kg/m^3
acceleration due to gravity 9.8 m/sec^2
Avogadro's number 6.02×10^{23} (# per mole)

Formulas

$$P(t) = \frac{1}{\beta}\left(1 - \frac{Q(t)}{Q_\infty}\right)Q(t)$$

$$Q(t) = \frac{Q_\infty}{1 + Ae^{-t/\beta}}$$

$$P(t) = P_0\left(\frac{Q_\infty}{Q_0}\right)^2 \frac{e^{-t/\beta}}{(1 + Ae^{-t/\beta})^2}$$

$$\beta = (Q_\infty - Q_0)\frac{Q_0}{Q_\infty P_0}$$

$$t_m = \left(1 - \frac{Q_0}{Q_\infty}\right)\frac{Q_0}{P_0}\ln\left(\frac{Q_\infty}{Q_0} - 1\right)$$

$$P_m = P(t_m) = \frac{Q_\infty^{\ 2} * P_0}{4Q_0(Q_\infty - Q_0)}$$

$$P = \frac{\Delta E}{\Delta t}$$

$$\eta = 1 - \frac{Q_L}{Q_H}$$

$$\eta_{carnot} = 1 - \frac{T_L}{T_H}$$

$$COP = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$

$$E = \frac{hc}{\lambda}; \quad hc = 1.98x10^{-25}\,Jm$$

$$hc = 1.23x10^{-6}\,eV \cdot m$$

$$P = I^2 R$$

$$\frac{P}{A} = \varepsilon\sigma T^4 \qquad \sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$$

$$I_0 \frac{\pi R^2}{4\pi R^2} = 342\ W/m^2$$

$$\tfrac{1}{4}I_0 = \tfrac{1}{4}\alpha I_0 + I_A$$

$$\lambda_m[\mu m] = \frac{2898}{T(K)}$$

$$E_{pot} = mgh = \rho Vgh$$

$$E_{kin} = \frac{1}{2}mv^2$$

$$\frac{P}{A} = 6.1x10^{-4}v^3[kW/m^2]$$

$$A = \pi r^2 = \pi\left(\frac{d}{2}\right)^2$$

$$\frac{\Delta Q}{\Delta t} = \frac{A}{R}\Delta T = AU\Delta T$$

$$R = 1/k$$

$$Q = mC\Delta T$$

$$m = \rho V$$

$$F = ma = m\frac{\Delta v}{\Delta t}$$

$$V = IR$$

$$J = E^*cg \sim 1\ kW/m^3s\ {}^*T H^2$$

$$P = 0.59\ A/2(\rho u^3)$$

Periodic Table of the Elements

Key:

2	← Proton number
He	• Symbol
Helium	← Name of element
4	← Relative atomic mass

1 H Hydrogen 1																	2 He Helium 4
3 Li Lithium 7	4 Be Beryllium 9											5 B Boron 11	6 C Carbon 12	7 N Nitrogen 14	8 O Oxygen 16	9 F Fluorine 19	10 Ne Neon 20
11 Na Sodium 23	12 Mg Magnesium 24											13 Al Aluminium 27	14 Si Silicon 28	15 P Phosphorus 31	16 S Sulfur 32	17 Cl Chlorine 35.5	18 H Argon 40
19 K Potassium 39	20 Ca Calcium 40	21 Sc Scandium 45	22 Ti Titanium 48	23 V Vanadium 51	24 Cr Chromium 52	25 Mn Manganese 55	26 Fe Iron 56	27 Co Cobalt 59	28 Ni Nickel 59	29 Cu Copper 64	30 Zn Zinc 65	31 Ga Gallium 70	32 Ge Germanium 73	33 As Arsenic 75	34 Se Selenium 79	35 Br Bromine 80	36 Kr Krypton 84
37 Rb Rubidium 86	38 Sr Strontium 88	39 Y Yttrium 89	40 Zr Zirconium 91	41 Nb Niobium 93	42 Nb Niobium 96	43 Tc Technetium 98	44 Ru Ruthenium 101	45 Rh Rhodium 103	46 Pd Palladium 106	47 Ag Silver 108	48 Cd Cadmium 112	48 In Indium 115	50 Sn Tin 119	51 Sb Antimony 122	52 Te Tellurium 128	53 I Iodine 127	54 Xe Xenon 131
55 Cs Cesium 133	56 Ba Barium 137	57 La Lanthanum 139	72 Hf Hafnium 179	73 Ta Tantalum 181	74 W Tungsten 184	75 Re Rhenium 186	76 Os Osmium 190	77 Ir Iridium 192	78 Pt Platinum 195	79 Au Gold 197	80 Hg Mercury 201	81 Tl Thallium 204	82 Pb Lead 207	83 Bi Bismuth 209	84 Po Polonium 210	85 At Astatine 210	86 Rn Radon 222
87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	104 Unq Unnilquadium 257	105 Unp Unnilpentium 260	106 Unh Unnilhexium 263	107 Uns Unnilseptium 262	108 Uno Unniloctium 265	109 Une Unnilennium 266									

58 Ce Cerium 140	59 Pr Praseodymium 141	60 Nd Neodymium 144	61 Pm Promethium 147	62 Sm Samarium 150	63 Eu Europium 152	64 Gd Gadolinium 157	65 Tb Terbium 159	66 Dy Dysprosium 136	67 Ho Holmium 165	68 Er Erbium 167	69 Tm Thulium 169	70 Yb Ytterbium 173	71 Lu Lutetium 175
90 Th Thorium 232	91 Pa Protactinium 231	92 U Uranium 238	93 Np Neptunium 237	94 Pu Plutonium 244	95 Am Americium 243	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 249	99 Es Einsteinium 254	100 Fm Fermium 253	101 Md Mendelevium 256	102 No Nobelium 254	103 Lr Lawrencium 257

Heat of combustion (calorific value) of various fuels.

Fuel	MJ/kg	MJ/L
Wood green	~ 8	~ 6
Wood oven dry	~ 16	~ 12
Methane	56	0.038
petrol/gasoline	47	37
crude oil	44	35
Coal	27	