



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](#)

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**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](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

## 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:  ${}^2\text{D} + {}^3\text{T} \rightarrow {}^4\text{He} + \text{n} + \text{Energy}$  begin to occur?

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

*Fusion of  ${}^2\text{D}$  and  ${}^2\text{T}$  can occur at temperatures on the order of  $10^8$  K.*

7. A small cabin style diesel-fired electrical generation station burns  $2 \times 10^3$  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  $\Rightarrow Q = V \cdot H = 20$  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

⇒  $\epsilon\sigma BT_e^4 = (S(1-a)/4) * ((1+\tau_s)/(1+\tau_L))$ , solve for  $\epsilon/S$ :  
 $\epsilon/S = (0.7/(4 \times 5.7 \times 10^{-8} \times 287^4)) (1.85/1.15) = 7.28 \times 10^{-4} \text{ m}^2/\text{W}$  substitute at  
 a new  $\tau_L$   
 $T_{\text{new}} = 289\text{K}$

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  $900 \text{ kWh}\cdot\text{m}^{-2}$  and that the solar cell has a typical efficiency of 15%.

- A.  $42 \text{ km}^2$   
**B.  $81 \text{ km}^2$**   
 C.  $102 \text{ km}^2$   
 E.  $1640 \text{ km}^2$

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,  $\eta_{sc}$  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  $E_{sc} = 11 \text{ TWh}$  and solving for  $A_{sc}$ :

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

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
- fusion,
  - fission,
  - combustion (burning),
  - emission of radiation.
13. Photovoltaic cells converting sunlight to electricity can be built with
- fissile materials,
  - semiconductor materials,
  - tritium,
  - helium.
14. A star generates energy by nuclear fusion reaction of H nuclei into helium
- $$4p \rightarrow {}^4_2\text{He} + 2e^+ + 2\nu + 18.3 \text{ MeV}.$$
- It fuses  $6 \times 10^8$  tons of hydrogen per second. What is the total energy in MeV the star produces per second?
- $3.14 \times 10^{10}$  MeV per sec
  - $1.65 \times 10^{39}$  MeV per sec
  - $2.06 \times 10^{-11}$  MeV per sec
  - $6.02 \times 10^{64}$  MeV per sec

Solution:

$6 \times 10^8$  tons of hydrogen  $\Rightarrow 6 \times 10^{14}$  g of hydrogen  $\Rightarrow$   
 number of  ${}^1\text{H} = 6 \times 10^{14} \times 6.02 \times 10^{23} = 3.61 \times 10^{38}$  atoms  $\Rightarrow$   
 $3.61 \times 10^{38} / 4 = 9.03 \times 10^{37}$  reactions  $\Rightarrow$   
 $9.03 \times 10^{37} \times 18.3 = 1.65 \times 10^{39}$  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  $1 \times 2.5$  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:

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

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


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  $1.3 \times 10^{24} \text{ cm}^3$  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)  $(1.3 \times 10^{24} \text{ cm}^3)(1.02 \text{ g/cm}^3) = 1.33 \times 10^{24} \text{ g H}_2\text{O}$ ;  $\sim 2/18$  of this is hydrogen, and  $2.8 \times 10^{-4}$  of that is Deuterium, so  $4.13 \times 10^{19} \text{ g D}$ . Atomic number 2  $\rightarrow$  each 2 grams contains  $6.02 \times 10^{23}$  atoms. It takes two D for each fusion event.  Energy available  $(1.24 \times 10^{43} \text{ atoms}/2(\text{atoms/fusion}))(4 \times 10^6 \text{ eV/fusion})(1.6 \times 10^{-19} \text{ J/eV}) = 3.97 \times 10^{30} \text{ J}$  (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 =  $(1/0.5) (2 \times 10^{12} \text{ J/s}) (3.15 \times 10^7 \text{ s/year}) = 1.26 \times 10^{20} \text{ J}$  (Total available)/(use per year)  $\sim 3 \times 10^{10}$  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<sup>2</sup>/day, what area is required (at that location) to supply the energy needs of the earth?

Solution:

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

## APPENDIX

### Energy conversion factors

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

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  $1.02 \times 10^3 \text{ kg/m}^3$

density of air  $\sim 1.2 \text{ kg/m}^3$

acceleration due to gravity  $9.8 \text{ m/sec}^2$

Avogadro's number  $6.02 \times 10^{23}$  (# per mole)



## Formulas

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

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

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

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

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

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

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

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

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

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

$$E = \frac{hc}{\lambda}; \quad hc = 1.98 \times 10^{-25} \text{ J}\cdot\text{m}$$

$$hc = 1.23 \times 10^{-6} \text{ eV} \cdot \text{m}$$

$$P = I^2 R$$

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

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

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

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

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

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

$$\frac{P}{A} = 6.1 \times 10^{-4} v^3 [\text{kW/m}^2]$$

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

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

$$R = 1/k$$

$$Q = mC\Delta T$$

$$m = \rho V$$

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

$$V = IR$$

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

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

## Periodic Table of the Elements

1 <b>H</b> <small>Hydrogen 1</small>																	2 <b>He</b> <small>Helium 4</small>				
2 <b>Li</b> <small>Lithium 3</small>	3 <b>Be</b> <small>Beryllium 9</small>															5 <b>B</b> <small>Boron 11</small>	6 <b>C</b> <small>Carbon 12</small>	7 <b>N</b> <small>Nitrogen 14</small>	8 <b>O</b> <small>Oxygen 16</small>	9 <b>F</b> <small>Fluorine 19</small>	10 <b>Ne</b> <small>Neon 20</small>
11 <b>Na</b> <small>Sodium 23</small>	12 <b>Mg</b> <small>Magnesium 24</small>															13 <b>Al</b> <small>Aluminum 27</small>	14 <b>Si</b> <small>Silicon 28</small>	15 <b>P</b> <small>Phosphorus 31</small>	16 <b>S</b> <small>Sulfur 32</small>	17 <b>Cl</b> <small>Chlorine 35.5</small>	18 <b>Ar</b> <small>Argon 40</small>
19 <b>K</b> <small>Potassium 39</small>	20 <b>Ca</b> <small>Calcium 40</small>	21 <b>Sc</b> <small>Scandium 45</small>	22 <b>Ti</b> <small>Titanium 48</small>	23 <b>V</b> <small>Vanadium 51</small>	24 <b>Cr</b> <small>Chromium 52</small>	25 <b>Mn</b> <small>Manganese 55</small>	26 <b>Fe</b> <small>Iron 56</small>	27 <b>Co</b> <small>Cobalt 59</small>	28 <b>Ni</b> <small>Nickel 59</small>	29 <b>Cu</b> <small>Copper 64</small>	30 <b>Zn</b> <small>Zinc 65</small>	31 <b>Ga</b> <small>Gallium 70</small>	32 <b>Ge</b> <small>Germanium 73</small>	33 <b>As</b> <small>Arsenic 75</small>	34 <b>Se</b> <small>Selenium 79</small>	35 <b>Br</b> <small>Bromine 80</small>	36 <b>Kr</b> <small>Krypton 84</small>				
37 <b>Rb</b> <small>Rubidium 86</small>	38 <b>Sr</b> <small>Strontium 88</small>	39 <b>Y</b> <small>Yttrium 89</small>	40 <b>Zr</b> <small>Zirconium 91</small>	41 <b>Nb</b> <small>Niobium 93</small>	42 <b>Nb</b> <small>Niobium 93</small>	43 <b>Tc</b> <small>Technetium 98</small>	44 <b>Ru</b> <small>Ruthenium 101</small>	45 <b>Rh</b> <small>Rhodium 103</small>	46 <b>Pd</b> <small>Palladium 106</small>	47 <b>Ag</b> <small>Silver 108</small>	48 <b>Cd</b> <small>Cadmium 112</small>	49 <b>In</b> <small>Indium 115</small>	50 <b>Sn</b> <small>Tin 119</small>	51 <b>Sb</b> <small>Antimony 122</small>	52 <b>Te</b> <small>Tellurium 128</small>	53 <b>I</b> <small>Iodine 127</small>	54 <b>Xe</b> <small>Xenon 131</small>				
55 <b>Cs</b> <small>Cesium 133</small>	56 <b>Ba</b> <small>Barium 137</small>	57 <b>La</b> <small>Lanthanum 139</small>	72 <b>Hf</b> <small>Hafnium 179</small>	73 <b>Ta</b> <small>Tantalum 181</small>	74 <b>W</b> <small>Tungsten 184</small>	75 <b>Re</b> <small>Rhenium 186</small>	76 <b>Os</b> <small>Osmium 190</small>	77 <b>Ir</b> <small>Iridium 192</small>	78 <b>Pt</b> <small>Platinum 195</small>	79 <b>Au</b> <small>Gold 197</small>	80 <b>Hg</b> <small>Mercury 201</small>	81 <b>Tl</b> <small>Thallium 204</small>	82 <b>Pb</b> <small>Lead 207</small>	83 <b>Bi</b> <small>Bismuth 209</small>	84 <b>Po</b> <small>Polonium 210</small>	85 <b>At</b> <small>Astatine 210</small>	86 <b>Rn</b> <small>Radon 222</small>				
87 <b>Fr</b> <small>Francium 223</small>	88 <b>Ra</b> <small>Radium 226</small>	89 <b>Ac</b> <small>Actinium 227</small>	104 <b>Unq</b> <small>Unquadrium 257</small>	105 <b>Unp</b> <small>Unpentium 260</small>	106 <b>Unh</b> <small>Unhexium 263</small>	107 <b>Uns</b> <small>Unseptium 262</small>	108 <b>Uno</b> <small>Unoctium 265</small>	109 <b>Une</b> <small>Unennium 266</small>													

— Proton number  
 • Symbol  
 — Name of element  
 — Relative atomic mass

58 <b>Ce</b> <small>Cerium 140</small>	59 <b>Pr</b> <small>Praseodymium 141</small>	60 <b>Nd</b> <small>Neodymium 144</small>	61 <b>Pm</b> <small>Promethium 147</small>	62 <b>Sm</b> <small>Samarium 150</small>	63 <b>Eu</b> <small>Europtium 152</small>	64 <b>Gd</b> <small>Gadolinium 157</small>	65 <b>Tb</b> <small>Terbium 159</small>	66 <b>Dy</b> <small>Dysprosium 166</small>	67 <b>Ho</b> <small>Holmium 165</small>	68 <b>Er</b> <small>Erbium 167</small>	69 <b>Tm</b> <small>Thulium 169</small>	70 <b>Yb</b> <small>Ytterbium 173</small>	71 <b>Lu</b> <small>Lutetium 175</small>
90 <b>Th</b> <small>Thorium 232</small>	91 <b>Pa</b> <small>Protactinium 231</small>	92 <b>U</b> <small>Uranium 238</small>	93 <b>Np</b> <small>Neptunium 237</small>	94 <b>Pu</b> <small>Plutonium 244</small>	95 <b>Am</b> <small>Americium 243</small>	96 <b>Cm</b> <small>Curium 247</small>	97 <b>Bk</b> <small>Berkelium 247</small>	98 <b>Cf</b> <small>Californium 249</small>	99 <b>Es</b> <small>Einsteinium 254</small>	100 <b>Fm</b> <small>Fermium 253</small>	101 <b>Md</b> <small>Mendelevium 256</small>	102 <b>No</b> <small>Nobelium 254</small>	103 <b>Lr</b> <small>Lrerenium 257</small>

### 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	