NTNU – Trondheim
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Department of Physics

Examination paper for FY2290: Energy Resources - pages 1-11

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Examination date: 25-05-2022
Examination time: 15:00 – 19:00
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 Date 18.05.2022
Signature

Part 1. Multiple Choice Questions (60%).

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 – not the real correct answers!):

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. Using the BP statistical review report, recall what are the main sources of energy for electricity production in Europe, North America and Asia.

A. Europe - bioenergy , North America - nuclear , Asia - hydro
B. Europe - hydro , North America - oil , Asia - coal
C. Europe - nuclear , North America - gas , Asia – coal
D. Europe - solar , North America - oil , Asia – coal

2. What is the part of nuclear energy according to the world consumption graph?

A. 2%
B. 4%
C. 15%
D. 23%

3. How much energy do you need to heat the water in the shower from 10C to 40 C flowing at the rate of 20 L/min for 8 min.

A. 2 mJ
B. 20 mJ
C. 200 mJ
D. 2 J

Solution: $Q = cpm\Delta T$ ~= (4.18 J/g · K)(160 L)(1 kg/L)(30 K) $\underline{\text{~= 20 MJ}}$

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

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

Fusion of ^{2}D *and* ^{2}T *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:*
$\varepsilon/S = (0.7/(4\text{x}5.7\text{x}10^{-8}\text{x}287^4))\ (1.85/1.15) = 7.28\text{x}10^{-4} m^2/W$ 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= $E_{sc}/E_{sun}\,\eta_{sc} = 11\text{x}10^{12}\ Wh / 900\text{x}10^3 Wh/m^2 \text{ x } 0.15 = 8.15 \text{ x } 10^7\ m^2 \sim 81\ \text{km}^2$

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

   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

$$4p \rightarrow {}^4_2He + 2e^+ + 2\nu + 18.3\ MeV.$$

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

15. The world consumption of primary energy in 2020 fell down to 13200 MTOE. Assume that the wind blows at 13m/s for 1/3 of the time (and that there is no wind at other times), that the efficiency of a wind turbine is 70% of the maximum theoretical value and the density of air is 1.2 kg/m^3. How many wind turbines with a diameter of 60m would be needed to supply this total energy?

A. $1.1\text{x}10^4$ turbines
B. $5.6\text{x}10^7$ turbines
C. $3.3\text{x}10^7$ turbines
D. $1.3\text{x}10^8$ turbines

Solution: 1320 MTOE = 5.5×10^{20} J, A = 2827 m^2
$P_t = (0.5 \times \rho \times A \times u_0^3 \times 0.7 \times 0.59)/3$ = 513 kW per turbine = 1.62×10^{13} J/(turbine.year), so
3.28×10^7 turbines are required.

Part 2. Calculations (40%)

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 in all details!
The answers can be written by hand.

1. 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. (5%)

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. 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. (5%)

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

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

a) What is the total energy in Joules available from this Deuterium by D-D fusion? Assume 4. 0 MeV per fusion event. (5%)

Solution:

a)(1.3 x 10^{24} cm^3)(1.02g/ cm^3)=1.33 x 10^{24} g H_2O; ~2/18 of this is hydrogen, and 2.8 x 10^{-4} of that is Deuterium, so 4.13x10^{19}g D. Atomic number 2 -> each 2 grams contains 6.02x10^{23}atoms. It takes two D for each fusion event. Energy available (1.24 x 10^{43}atoms/2(atoms/fusion))(4 x 10^6eV/fusion)(1.6x10^{-19}J/eV)=3.97x10^{30}J (answers that had correct formulation without numerical values for constants received full credit)

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

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. Nuclear energy (15%)
(a) What is the atomic mass number (A) and charge (Z) of the nucleus born as a result of α-decay of ${}^{238}_{92}U$ (5%)

Solution: α-decay is given by ${}^{A}_{Z}Y \rightarrow {}^{A-4}_{Z-2}X + {}^{4}_{2}He$,
A=238, Z=92, thus the mass number $A-4=234$, charge $Z-2=90$.

(b) The half-life of α-decay of isotope ${}^{238}_{92}U$ equals 4.46×10^{9} years. Consider N_0 nuclei of ${}^{238}_{92}U$. What is the fraction of these nuclei that decay in 10^{6} years? (5%)

Solution:
Decay law: $N(t) = N_0\, e^{-\lambda t}$, where $\lambda = \frac{\ln 2}{T_{1/2}}$
$T_{1/2}$=4.46×10^{9}, thus λ=1.5541×10^{-10}, t=10^{6}
Decayed fraction: $\frac{N_0 - N(t)}{N_0} = 1 - e^{-\lambda t} \approx \lambda t = 0.0001554 = 0.015\%$

(c) The energy release due to each act of α-decay of isotope ${}^{238}_{92}U$ is equal to 4.196MeV. How much energy is released in a sample of ${}^{238}_{92}U$ containing 10^{3} nuclei in 10^{6} years? (5%)

Solution:
Released energy = 0.00015541×10^{3}×4.196=0.65 MeV= 1.04×10^{-13} J = 0.1 pJ

Note: In this problem students needed to compute expected (mean) number of decays and corresponding expected energy release. Then, one can also provide the interpretation of the results. It is essential to demonstrate understanding that (i) the decay law determines the expected mean quantities and (ii) it does not predict an outcome of a single experiment.

5. The photovoltaics (5%)

The world primary energy consumption in 2020 was slightly above 13 000 Mtoe. Assuming that flat panel solar cells at a sunny location in Spain can harvest 8 kWh/m2/day, what area is required (at that location) to supply the energy needs of the earth?

Solution:

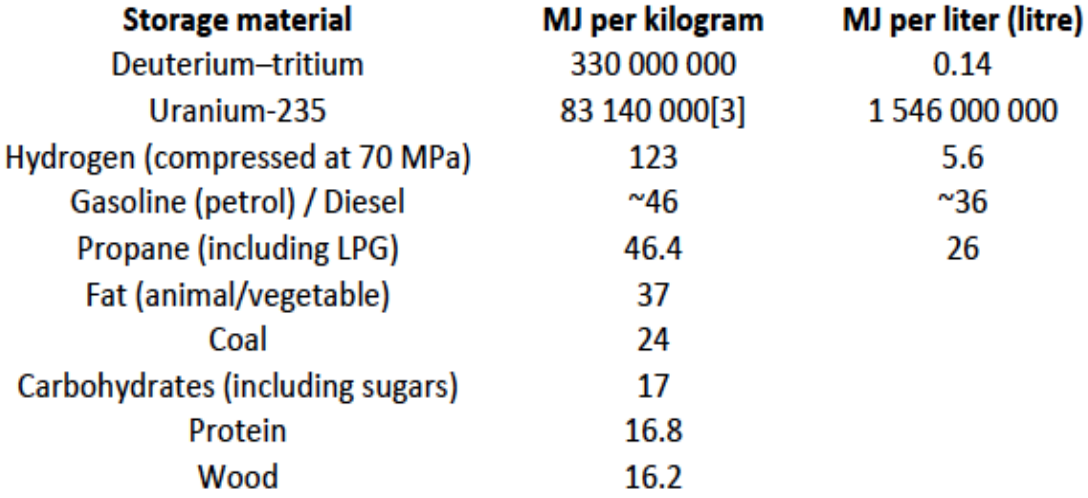
13000Mtoe= 13x 10^{9}toe/(8.6 x10^{-5}toe/kWhr)=1.5x10^{14}kWhr/year (8kWhr/day-m^{2})*365 =

$2920 kWhr/m^2$ $1.5x10^{14} kWhr/(2920 kWhr/m^2)=$**$\underline{5.2x10^{10}m^2}$**

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

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

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

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

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

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

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

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

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

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

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

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

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

$$P=I^2R$$

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

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

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

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

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

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

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

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

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

$$R=1/k$$

$$Q=mC\Delta T$$

$$m=\rho V$$

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

$$V=IR$$

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

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

Periodic Table of the Elements

1 **H** Hydrogen 1																	2 **He** Helium 4
2 **Li** Lithium 3	3 **Be** Beryllium 9					2 **He** Helium 4	**← Proton number** **← Symbol** **← Name of element** **← Relative atomic mass**					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** Aluminum 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 **Ti** 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** Neodymin 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** Yuterbium 173	71 **Lu** Lutertium 175	
			90 **Th** Thorium 232	91 **Pa** Proactinum 231	92 **U** Uranium 238	93 **Np** Neptunium 237	94 **Pu** Plutonium 244	95 **Am** Americium 243	96 **Cm** Curium 247	97 **Bk** Berkerium 247	98 **Cf** Californium 249	99 **Es** Einsteinium 254	100 **Fm** Fermium 253	101 **Md** Mendelevium 256	102 **No** Nobelium 254	103 **Lr** Lawrensium 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	