ℹ Department of Physics

Examination paper for TFY4225 Nuclear and Radiation Physics

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Examination date: 27.11.2019
Examination time: 15:00 – 19:00

Permitted examination support material: Code C

- **Simple specified calculator**
- **Barnett & Cronin: Mathematical Formulae**
- **Rottmann: Matematische Formelsammlung**

Language: English

Other information: The exam might be answered in English or Norwegian. The exam has five problems 1 to 5, which are weighted equally.

1 A central model in nuclear physics is the nuclear shell model.

a) Describe the key element of this model that contributed to bring nuclear physics a major step forward.

b) What was the two main success criteria for this model?

c) Determine the spin and parity of ${}^{35}_{17}Cl$ in the ground state and suggest three possible spin-parity states of excited states. The sequence of the lower states in the shell model is 1s1/2, 1p3/2, 1p1/2, 1d5/2, 2s1/2, 1d3/2.

d) Use angular momentum conservation to determine the multipolarity of the gamma emission from a $1/2^+$ excited state to the ground state in ${}^{35}_{17}Cl$. How would you expect the lifetime of this excited state to be compared with common lifetimes of excited states in nuclei?

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2 a) Your X-ray source is emitting 150 keV photons. How many photons must be emitted from this source if you want to get 100 counts from the primary beam in a 5 mm thick CsI scintillator detector placed behind 20 cm of water?

The linear attenuation coefficients of water and CsI at 100 keV are 0.227 cm^{-1} and 9.16 cm^{-1}, respectively.

b) Photons interact with matter through three primary processes. Name these processes.

c) How is the cross section for each of these processes related to the atomic number, Z, of the material and the photon energy, E?

d) In the hospital a new linear accelerator for radiotherapy of cancer patients has been purchased. The accelerator can generate photons with an energy of up to 4 MeV. You are chief physicist responsible for the installation and radiation protection, including to design a new room with concrete walls. How thick does the concrete walls need to be to attenuate the photon beam by a factor of 10^6?

The density of concrete is 2200 kg/m^3 and the mass attenuation coefficient of concrete is 0.064 cm^2/g.

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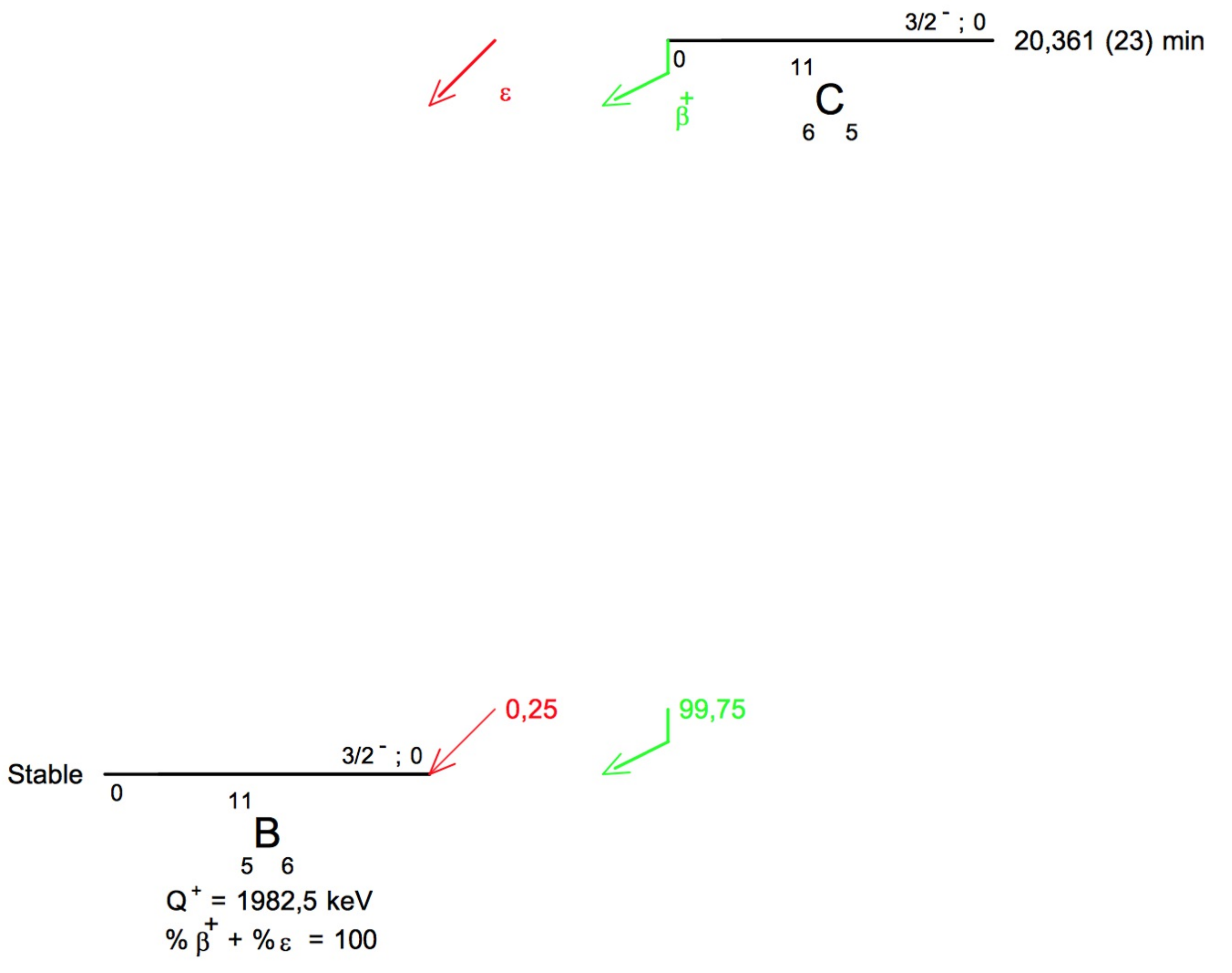
3 a) Describe briefly the main principles of PET imaging.

b) ^{11}C can be used in PET imaging and can be produced in a cyclotron via the reaction $^{14}N(p, \alpha)^{11}C$. You are working at the cyclotron and responsible for producing ^{11}C for patient examinations at the PET facility. Each morning you must therefore deliver 95% of the maximum ^{11}C activity at 08:00. When do you need to start the ^{11}C production?



c) Derive the expression of the cyclotron frequency and give an expression for the final proton kinetic energy. The centripetal force is given by mv^2/r.

d) If the cyclotron has a radius of 79 cm, what is the magnetic field required to reach 30 MeV for the protons?

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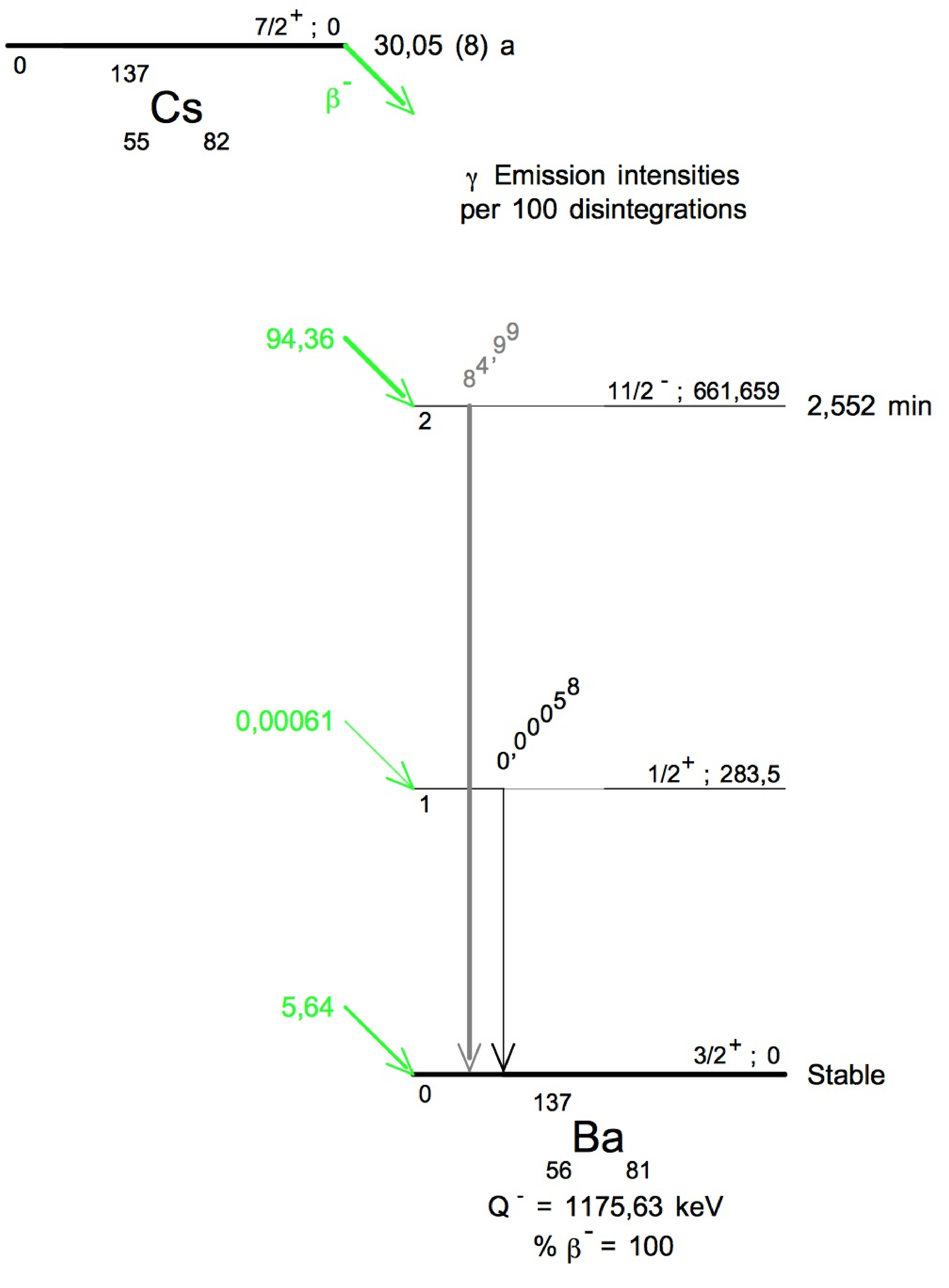
4 a) One of the projects this fall was about the Chernobyl accident.

- What was the reactor used to before the accident happened?

- In the reactor they used a so-called moderator. What is a moderator and why was it used? What material was the moderator in the Chernobyl reactor?
- Why did the accident happen?
- After the accident, many (especially children) got cancer. What was the most frequent type of cancer occurring and why that particular type of cancer?

b) Due to weather conditions radioactive downfall from Chernobyl occurred also in many areas in North-Western Europe, including Norway. In Norway we still monitor Cesium-137 (Cs-137) levels in for instance reindeer and sheep.

Reindeer steak is your favourite Sunday dinner and you therefore make a 250 g steak for dinner every weekend. What is your annual radiation dose based on Cs-137 from the reindeer meals? See the figure for information about the Cs-137 decay. You can assume even distribution of radioactivity in your body and that the meet has an activity of 3000 Bq/kg. Cs-137 has a biological half-life of 70 days.



c) For radiation protection purposes, there is an annual limit for radiation exposure to the public. What is this limit? Based on the intake of reindeer meet only, is it safe to eat a 250 g steak every Sunday?

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5 A beam of alpha particles is directed at a potential barrier as indicated in the figure. The beam has a high flux, Γ = 6 x 10^{22} particles/sec. The energy of the alpha particles is E = 5 MeV, the potential barrier height is V_B = 85 MeV and its width is L = 10 fm. You may assume the alpha rest mass to be $m_\alpha c^2$ = 4000 MeV (and $\hbar c \approx$ 200 MeV fm, with $c \approx$ 3 x 10^8 ms^{-1}).

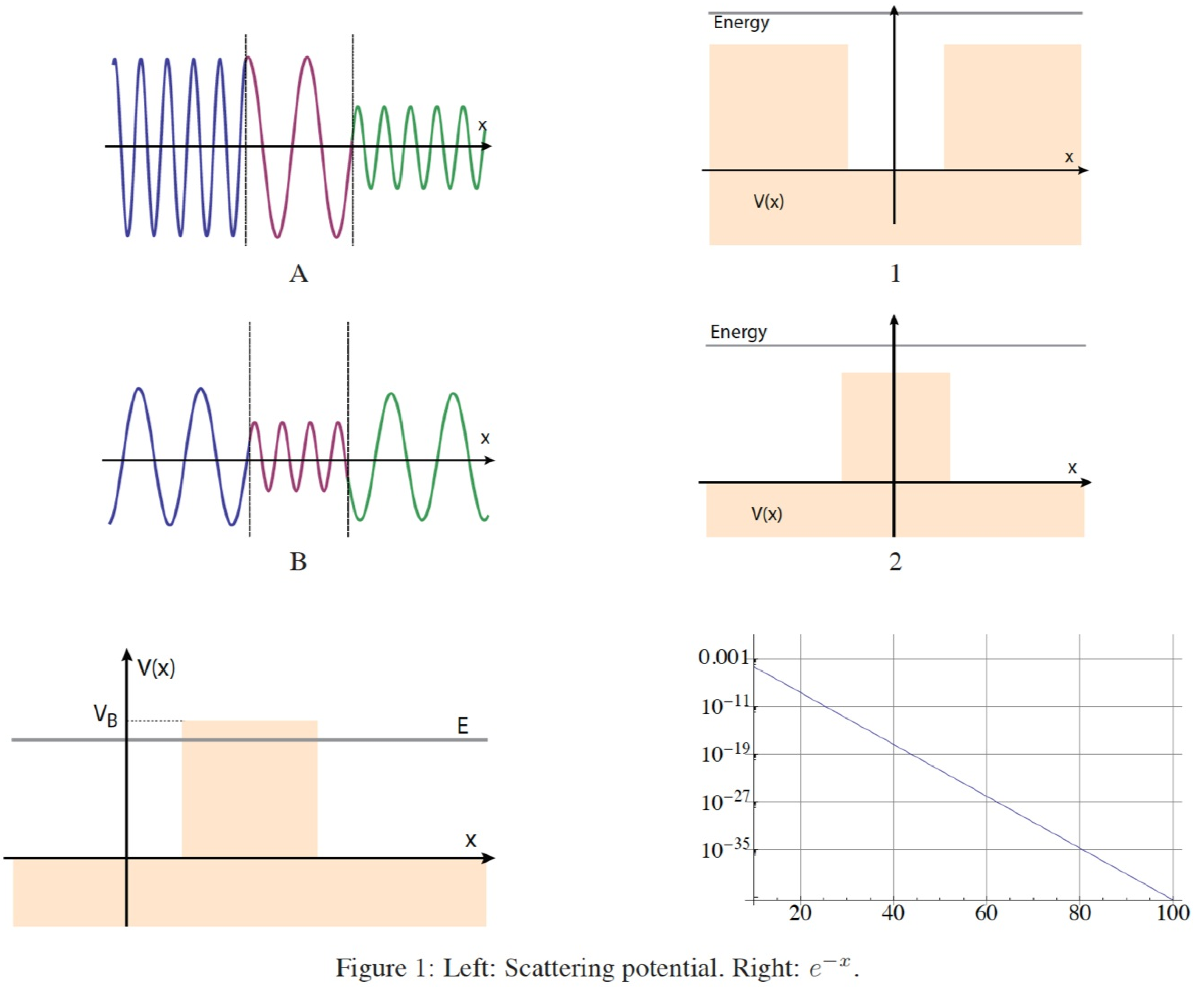

Figure 1: Left: Scattering potential. Right: e^{-x}.

a) Make a drawing of the eigenfunction for this problem, assuming the alpha particles are shot in from the left.

b) Estimate the probability of tunnelling, P_{tun}, through the barrier. Write the generic approximate formula for tunnelling and then estimate the numbers quantitatively (the plot can help you with a numerical estimate).

c) If the incoming beam is described by the wavefunction $\psi(x) = Ae^{ikx}$, calculate A that gives the flux $\Gamma = p(x)\nu$ (where $p(x)dx$ is the probability of finding the particle at $(x, x + dx)$ and ν is the particle velocity).

d) Assuming the flux of alphas emerging the barrier is $\Gamma_{tun} = P_{tun}\Gamma$, how long should you wait to see an alpha particle exit from the barrier? (hint: you need to calculate the time τ such that $\Gamma_{tun}\tau = 1$)

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