英

令和４年度 秋季募集

東北大学大学院工学研究科
量子エネルギー工学専攻入学試験

試験問題冊子
【専門科目　Specialized Subjects】

令和４年８月３１日（水）　10:00 － 11:00
Wednesday, August 31, 2022　10:00 － 11:00

Notice

1. Do not open this examination booklet until instructed to do so.

2. An examination booklet, answer sheets, draft sheets, and two subject selection forms are provided. Put your examinee number on each of the answer sheets, the draft sheets, and the forms.

3. Select two subjects from the nine subjects in the booklet. No more than one subject can be selected from Radiochemistry, Radiation Engineering, and Reactor Physics. Indicate your selection on the subject selection forms. Use two answer sheets for each subject.

4. At the end of the examination, double-check your examinee number and the selected subject on the answer sheets. Put your answer sheets in numerical order on top of the other sheets, place them beside the test booklet, and wait for collection by an examiner. Do not leave your seat before the examiner's instruction.

流 体 力 学　FLUID DYNAMICS

Consider a two-dimensional steady state potential flow of an inviscid incompressible fluid around a corner whose central angle is $2\pi - \theta_0$ (here, $0 < \theta_0 \le 2\pi$) as shown in Fig. 1. And its complex velocity potential, W, is given by

$$W = A z^{\alpha} .$$

Here, A and z are the complex constant and variable, respectively, given by

$$A = |A| e^{i\beta} \quad , \quad z = x + iy = re^{i\theta} \quad ;$$

where α is a positive constant and β is a constant of $-\pi < \beta < \pi$. Answer the following questions.

(1) Calculate the real and imaginary parts of W, and then obtain the velocity potential $\phi(r,\theta)$ and stream function $\psi(r,\theta)$.

(2) Using the result of question (1), obtain the radial velocity component $u_r(r,\theta)$ and the circumferential velocity component $u_\theta(r,\theta)$.

(3) Using the result of question (2), determine β from a boundary condition in terms of $u_\theta(r,0)$.

(4) Using the results of questions (2) and (3), determine α from a boundary condition in terms of $u_\theta(r,\theta_0)$.

(5) Using the results of questions (2), (3) and (4), obtain the velocity component in the x-direction, $u_x(r,\theta)$ and that in the y-direction, $u_y(r,\theta)$. And then explain the flow field near the origin O.

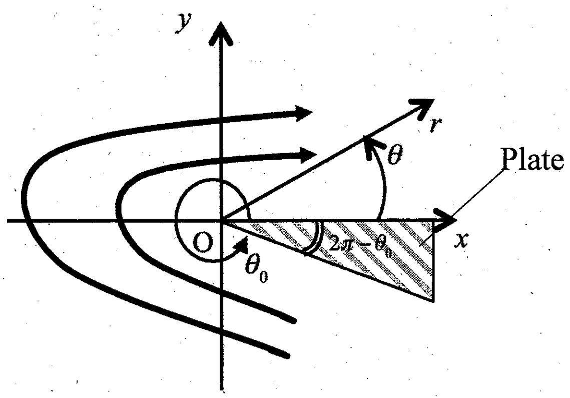


Fig. 1

電 磁 気 学　ELECTROMAGNETICS

As shown in Fig 1, a square loop with a side length of a is situated in a uniform magnetic field $\boldsymbol{B}(t) = B_0\boldsymbol{k}\sin(\omega t)$, where B_0, $\boldsymbol{k}$, ω, and t are a constant, a unit vector in the z-direction, angular frequency, and time, respectively. The square loop can rotate along the x-axis with an angular frequency of ω_L. The angle between the square loop and the xy-plane is denoted as θ, and the resistance of the square loop is R. Answer the following questions. Ignore the magnetic field generated by the induced current.

(1) Assume $\omega_L << \omega$ and answer the following questions.

a) Find the electromotive force induced in the square loop and the current flowing in the square loop when $\theta = 0$.

b) Find the electromotive force induced in the square loop and the current flowing in the square loop as a function of θ.

c) Find the maximum Joule's heat generated in the square loop and the condition of θ that maximizes Joule's heat.

(2) Assume $\omega_L = \omega$ and answer the following questions.

a) Find the maximum current flowing in the square loop and the angle θ at that time.

b) Find the total charge that moves in the square loop when the square loop rotates from $\theta = 0$ to $\pi/6$.

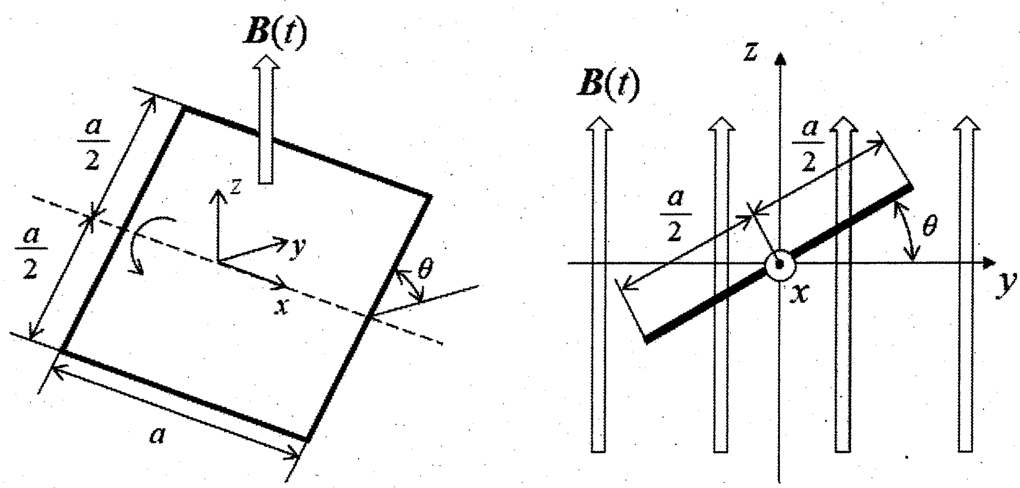


Fig. 1

量子力学 QUANTUM MECHANICS

Assuming that the relativistic effect in the kinetics can be ignored, answer the following questions using $\hbar = \dfrac{h}{2\pi}$, where h is Planck's constant.

(1) Consider a free particle with mass M enclosed in the region of $0 \le x \le d$ in one-dimensional space, where d is a positive constant. Answer the following questions.

a) Find the minimum kinetic energy of the free particle using the uncertainty relation between position and momentum.

b) Find the conditions of d in which the maximum de Broglie wavelength of the free particle is less than or equal to 10^{-9} m.

(2) When a potential $V(x)$ is an even function in one-dimensional space, wave functions of a particle in $V(x)$ are even or odd functions. Consider an electron with mass m confined in the following potential

$$V(x) = \begin{cases} +\infty & (x < -a) \\ 0 & (-a \le x \le a) \\ +\infty & (x > a) \end{cases},$$

where a is a positive constant. Answer the following questions.

a) Find the odd functions among the normalized wave functions of the electron.

b) Find the energy eigenvalues for the odd wave functions obtained in question a).

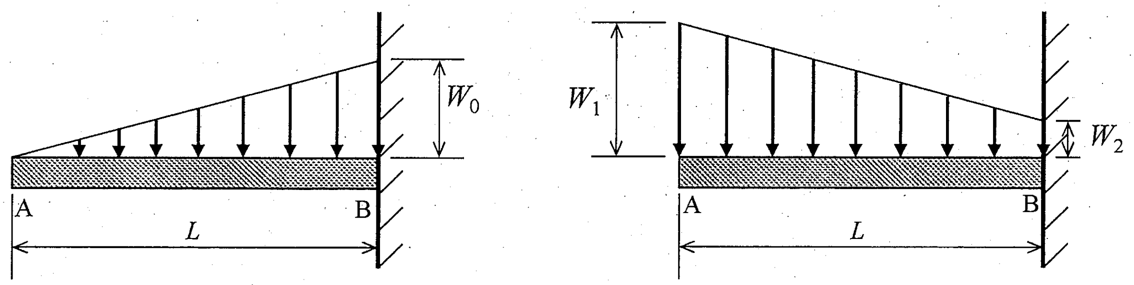
c) Find the expectation values of the position x for the odd wave functions obtained in question a).

材 料 力 学　STRENGTH OF MATERIALS

There are two cantilever beams, each subjected to a linearly distributed load as shown in Fig. 1. The length of the beams (from the free end A to the fixed end B) is L. Ignore the self-weight of the beams. Answer the following questions.

(1) For the case shown in Fig. 1 (a), find the reaction force and reaction moment at the fixed end, and then find the shear force and bending moment at any position between A and B. Also, schematically draw the shear force diagram and bending moment diagram. Note that W_0 is the load at the fixed end and the load at the free end is zero.

(2) For the case shown in Fig. 1 (b), find the reaction force and reaction moment at the fixed end, and then also find the shear force and bending moment at any position between A and B. Note that W_1 and W_2 are the load at the free end and the fixed end, respectively, and that $W_1 > W_2$.



(a)　　　(b)

Fig. 1

機械材料学　MECHANICAL MATERIALS

Answer the following questions about metals and alloys.

(1) At room temperature, the crystal structure of iron is the body-centered cubic structure. The density of iron at room temperature is 7.87 g/cm^3 and the atomic weight of iron is 55.8. Calculate the lattice parameter of the iron crystal at room temperature. Here, the Avogadro number is 6.0×10^{23}. Use $23.6^{1/3} = 2.86$ and $47.1^{1/3} = 3.61$, if necessary.

(2) Give the Miller index or indices of the slip system(s) of the face-centered cubic structure.

(3) Draw a schematic of the phase diagram of the Ni-Cu alloy forming a perfect solid solution. The melting points of Ni and Cu are 1453°C and 1085°C, respectively.

(4) Explain the age hardening in aluminum alloys.

(5) Calculate the self-diffusion coefficient D in a metal at 700 K, where the frequency term and the activation energy for self-diffusion is 1.00×10^{-5} m^2/s and 67.0 kJ/mol, respectively. The universal gas constant R is 8.3 J/(mol·K). Use the approximate equation $e^x = 10^{x/2.30}$, if necessary.

化 学 基 礎　CHEMISTRY BASICS

Answer the following questions.

(1) Consider the following descriptions of i) to v). If the underlined part of the description is correct, indicate "true". If the underlined part of the description is not correct, indicate "false" and revise the underlined part.

i) The electric conductivity of germanium decreases with an increase in temperature.

ii) In the Lewis definitions of acids and bases, an electron-pair donor and an electron-pair acceptor are a Lewis base and a Lewis acid, respectively.

iii) The order in the first ionization energies of nitrogen (N), oxygen (O), fluorine (F) and neon (Ne) is $N < O < F < Ne$.

iv) The electron affinity of fluorine is larger than that of chlorine.

v) Two anions "A", two anions "B", and a metal cation "M" form a tetra-coordinated complex. This complex has geometrical isomers when its structure is plane square, whereas this complex has no geometrical isomers when its structure is tetrahedral.

(2) Answer the following questions concerning ammonia.

a) The thermochemical equation of the ammonia formation is

$$N_2 + 3H_2 \rightarrow 2NH_3 \qquad \Delta H = -92\ \text{kJ}.$$

Indicate two types of operations that increase the amount of formed ammonia, based on this equation.

b) Assume that ammonia (gas) is absorbed in a 0.10 mol/L sulfuric acid solution of 100 mL until neutralization. Calculate the volume [mL] of the absorbed ammonia (gas) under the standard reference condition (273 K, 1.0×10^5 Pa).

c) The dissolution of NO_2, which is obtained by the oxidation of NH_3, into water forms nitric acid. Give the chemical reaction equation for the formation of nitric acid from NO_2 dissolved in water. In addition, explain the reason why iron is not corroded by the immersion in the concentrated nitric acid solution although iron is rusted in the humid air.

放射化学　RADIOCHEMISTRY

In 25 mL of a 0.10 mol/L HCl solution, 2.0×10^{5} Bq of ^{140}Ba is dissolved without stable isotope carrier. This solution is named as "solution A." Now, the ^{140}Ba in solution A is in radioactive equilibrium with the daughter nuclide ^{140}La.

Answer the following questions. In these questions, use the given values, *i.e.*, the half lives of ^{140}Ba and ^{140}La are 300 hours and 40 hours, respectively, $\log_e 2 = 0.70$, and Avogadro's constant is 6.0×10^{23} mol^{-1}. The significant figure is 2 digits.

(1) Show the decay mode of ^{140}Ba, and calculate mass [g] of barium in solution A.

(2) Calculate activity [Bq] of ^{140}La in solution A.

(3) Barium chloride and lanthanum chloride are added to solution A as the stable isotope carriers to make both barium and lanthanum concentrations 1.0×10^{-2} mol/L. Subsequently, sodium sulfate is added to this solution to make sodium sulfate concentration 5.0×10^{-3} mol/L. Soon after, white precipitate is formed in the solution. This precipitate is separated by filtration, then washed by pure water. This sequential procedure is conducted in a short time. Answer the following questions.

a) Show the chemical reaction formula that indicates the formation of the white precipitate.

b) Show the name and activity [Bq] of the radioactive nuclide contained in the white precipitate right after the collection procedure.

放射線工学 RADIATION ENGINEERING

1. Gamma rays with mono energy (E_γ[keV]) from a radioactive source are measured using a radiation detector. Gamma ray energy E_γ is <1000 keV. When energy resolution of the detector is in ideal condition, the energy spectrum shown in Figure 1 is obtained. In the spectrum, four components of peak A, peak B, continuum C, and, continuum D are observed. Answer the following questions assuming that all of electron beams induced by gamma rays stop inside of the detector.

(1) Explain what kind of interactions occurred inside of the detector on the formation process of the A, B, C and D components, respectively.

(2) When upper energy in the continuum component D is set to E_d [keV], sharp edge is formed at this energy. Explain the reason why the sharp edge is formed.

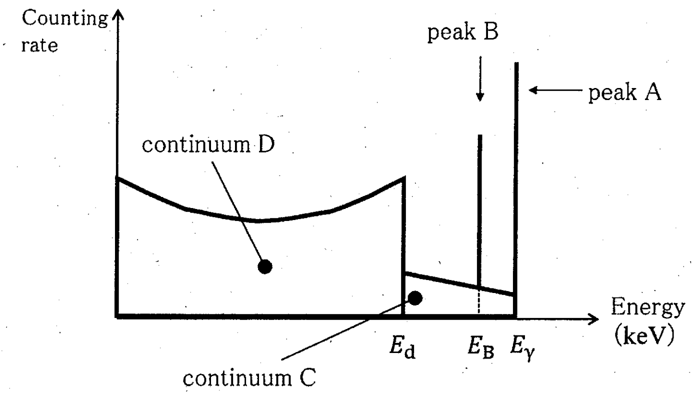


Fig. 1

2. After intake of a radionuclide into the body, accumulation of the radionuclide was observed in a specific organ immediately. Answer the following questions about this internal exposure.

(1) The physical half-life of this radionuclide is 30 years, and the biological half-life in this organ is 50 days. Find the effective half-life.

(2) In question (1), the radioactivity of this organ was 120 Bq immediately after the intake. Find the total decay number (cumulative radioactivity [MBq·s]) for a time sufficiently longer than the effective half-life after accumulation. It is assumed that there is no new accumulation in the organ and there is no increase or decrease in organ weight. Use $\log_e 2$ as 0.7, if necessary.

(3) Find the equivalent dose [Sv] when the total decay number of this organ is N [MBq·s]. Furthermore, find the effective dose [Sv] when internal exposure occurs only in this organ. It is assumed that the only radiation generated by the decay of this radionuclide is gamma rays, the conversion factor between cumulative radioactivity and absorbed dose [μGy / (MBq·s)] is 0.0025, and the tissue weighting factor of this organ is 0.05.

原子炉物理学　REACTOR PHYSICS

Answer the following questions.

(1) Figures 1–4 show the microscopic fission and capture cross-sections of ^{235}U and ^{238}U. Answer which of Figures 1–4 show the microscopic fission cross-section of ^{235}U and that of ^{238}U, together with the reasons.

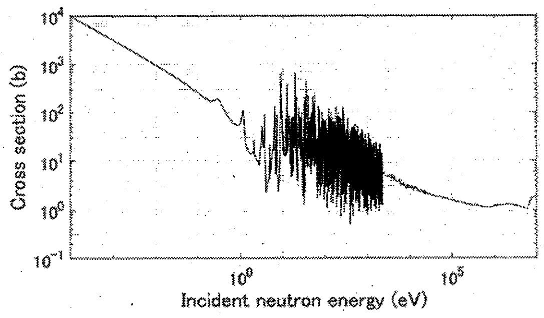


Fig. 1

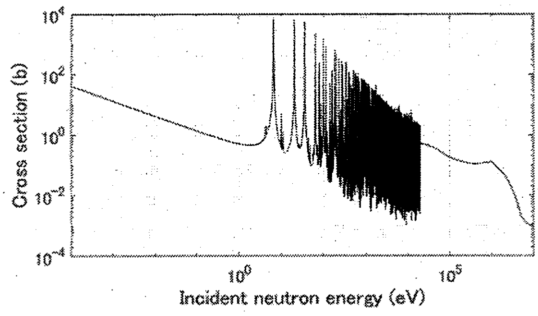


Fig. 2

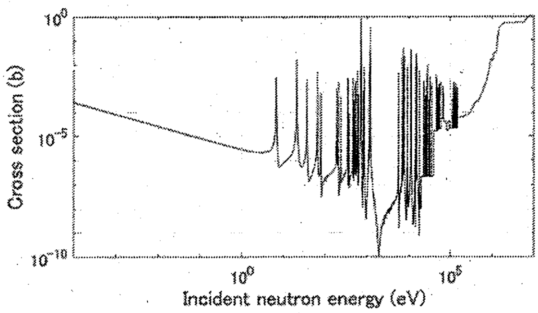


Fig. 3

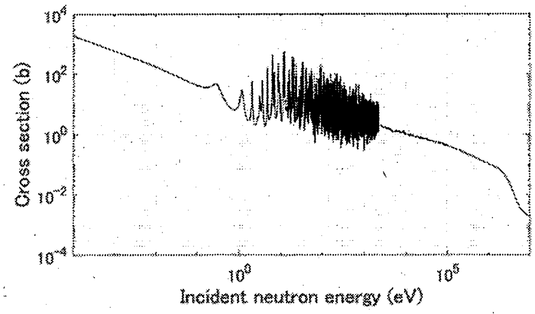


Fig. 4

(2) Assume that tritium (^3H) has an atomic mass of 3.0 and decays via beta decay with a half-life of 12 years. Calculate the radioactivity of 1 g of tritium in Bq, and answer the decay product(s) of tritium. Here, the Avogadro number is 6.0×10^{23} and use $\log_e 2 = 0.7$ if necessary.

(3) Consider a point neutron source in an infinitely large uniform medium. The source emits S neutrons per second isotopically. Assume that the neutron flux ϕ and neutron current density vector $\boldsymbol{J}$ satisfy the equation of continuity,

$$\nabla \cdot \boldsymbol{J} + \Sigma_a \phi = 0,$$

and the diffusion approximation,

$$\boldsymbol{J} = -D\nabla\phi,$$

where Σ_a and D stand for the macroscopic absorption cross-section of the medium and diffusion constant, respectively. Obtain ϕ as a function of the distance from the source, r. Here, the Laplacian in the one-dimensional spherical coordinate can be written as

$$\nabla^2 = \frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d}{dr}\right).$$