英

令和５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５年８月３０日(水)　　10:00 ～11:30
Wednesday, August 30, 2023　　10:00 ～11:30

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 entrance examination ID on each of the answer sheets, the draft sheets, and the forms.

3. Indicate your selection on the subject selection forms and the answer sheets. Use two answer sheets for each subject.

4. At the end of the examination, double-check your entrance examination ID 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

A cylinder of radius a with clockwise circulation Γ is placed in a uniform flow. Consider the flow around the cylinder as an inviscid and incompressible two-dimensional vortex-free flow. The origin is located on the center axis of the cylinder. The complex velocity potential $W(z)$ is given by

$$W(z) = U\left(z + \frac{a^2}{z}\right) + \frac{i\Gamma}{2\pi}\log_e\left(\frac{z}{a}\right),$$

where z is a complex variable in the polar form given by $z = re^{i\theta}$ where r, θ and i are radial and circumferential coordinates, and the imaginary unit, respectively, and U is a positive real number. The pressure far upstream of the cylinder p_∞ and the density of the fluid ρ are constant. When $\Gamma = 4\pi Ua$, answer the following questions.

(1) Obtain the velocity potential $\phi(r,\theta)$ and the stream function $\psi(r,\theta)$ of the flow field.

(2) Obtain the radial component V_r and the circumferential component V_θ of the flow velocity.

(3) Obtain the coordinates of a stagnation point in the flow field in polar coordinates, where $-\pi \leq \theta < \pi$. Then obtain the pressure at the stagnation point.

(4) Obtain the pressure profile $p(a,\theta)$ on the cylinder.

(5) Obtain the force acting on the cylinder due to the pressure. If necessary, use

$$\int_{\theta_1}^{\theta_2} \sin^2\theta \, d\theta = \left[-\frac{1}{4}\sin 2\theta + \frac{\theta}{2}\right]_{\theta_1}^{\theta_2},$$

$$\int_{\theta_1}^{\theta_2} \sin^3\theta \, d\theta = \left[\frac{1}{3}\cos^3\theta - \cos\theta\right]_{\theta_1}^{\theta_2}.$$

電磁気学 ELECTROMAGNETICS

Two parallel conducting wires having a distance a apart are situated on a plane perpendicular to a uniform magnetic field $\boldsymbol{B}$ as shown in Fig. 1. The wires are connected by a resister with resistance R and switch S. Switch S is initially open, and a conducting bar with mass m and resistance r slides inertially at a speed of v_0 in the x direction on the wires. Switch S is turned on when the conductive bar reaches $x = 0$, and the conducting bar stops after passing a certain distance. The friction forces between the conductive bar and the wires are negligibly small. Neglect the magnetic field generated by the induced current, the inductance and capacitance of a closed circuit formed when switch S is turned on. Answer the following questions.

(1) Find the current flowing through the conductive bar just after switch S is turned on. Explain the direction of the current.

(2) Find the Lorentz force acting on the conductive bar, and write the equation of motion of the conductive bar using $v(t)$, where $v(t)$ stands for the speed of the conductive bar at time t after switch S is turned on.

(3) Solve the equation of motion of the conductive bar in question (2) and find the position where the conductive bar stops in the x direction.

(4) Find the power delivered to the resister until the conductive bar stops after turning on switch S.

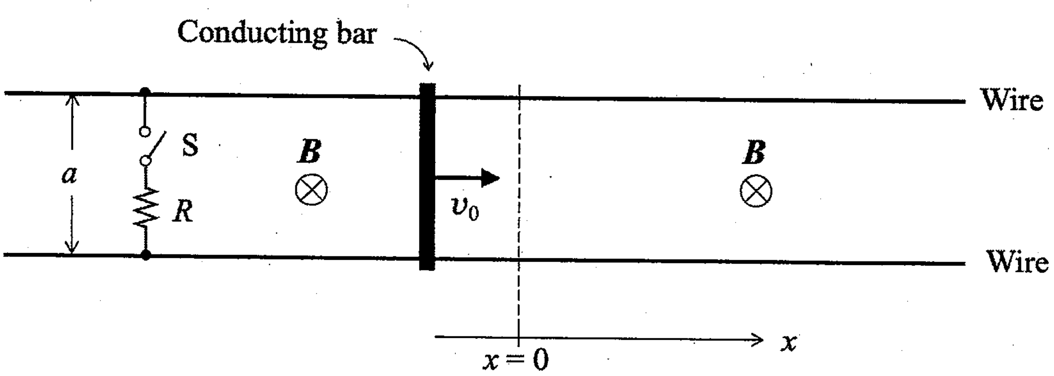

Fig. 1

量子力学 QUANTUM MECHANICS

In one-dimensional space, consider a particle of mass m and energy E which comes from $x = -\infty$ towards the following potential $V(x)$ defined by

$$V(x) = \begin{cases} 0 & (x < 0) \\ V_0 & (0 \leq x) \end{cases},$$

where V_0 is a constant, and $E > V_0 > 0$. Let $\varphi_1(x) = Ae^{ikx} + Be^{-ikx}$ and $\varphi_2(x) = Ce^{i\alpha x}$ be the wave functions of the particle for $x < 0$ and $0 \leq x$, respectively, where $k > 0$, $\alpha > 0$, and A, B and C are constants. Assuming that the relativistic effect in the kinematics can be ignored, answer the following questions using $\hbar = h/(2\pi)$, where h is Planck's constant.

(1) Write the time-independent Schrödinger equations for $x < 0$ and $0 \leq x$.

(2) Obtain k and α.

(3) Show the relationships of A, B and C based on the boundary conditions at $x = 0$.

(4) Describe $|B/A|^2$ and $|C/A|^2$ using k and α.

(5) Calculate $|B/A|^2 + (\alpha/k)|C/A|^2$ and explain the physical meaning of the result.

材料力学 STRENGTH OF MATERIALS

Consider a thin-walled cylinder of inner diameter D and thickness of the cylindrical body t, as shown in Fig. 1. The cylinder is filled with a gas of internal pressure P. Answer the following questions. Here, consider the material to yield when the maximum shear stress reaches its inherent limit value.

(1) Determine the stresses in the axial and the circumferential directions in the cylindrical body of the cylinder, respectively.

(2) Draw the Mohr's circle for the stress state of the cylindrical body of the cylinder.

(3) The compressive force F was applied at both ends of the cylinder in the axial direction as shown in Fig. 2. The cylindrical body of the cylinder yielded when the external force reached F_C. When strength of a solid bar made of the same material as the cylinder was evaluated by a uniaxial tensile test, the bar yielded when the tensile stress reached σ_Y. Determine the σ_Y using the parameters P, t, D, and F_C. Neglect buckling, stress concentration, and changes in internal pressure and in circumferential stress during the compression.

(4) A torsion was applied to a solid round bar of diameter d_0 which is made of the same material as the cylinder. Using P, t, D, d_0, and F_C in question (3), answer the torsional moment required for the round bar to yield.

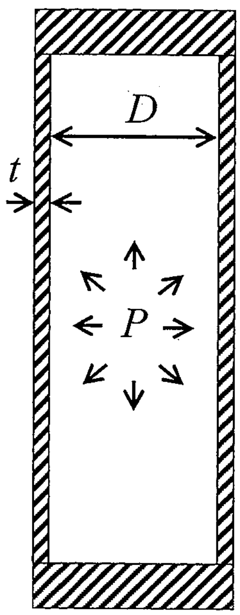

Fig. 1

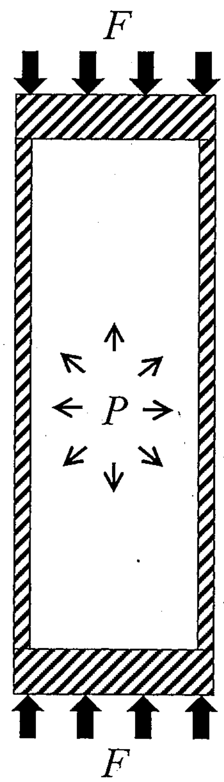

Fig. 2

機械材料学　MECHANICAL MATERIALS

Answer the following questions.

(1) Determine the Miller indices for the planes in the unit cell shown in Fig.1, respectively.

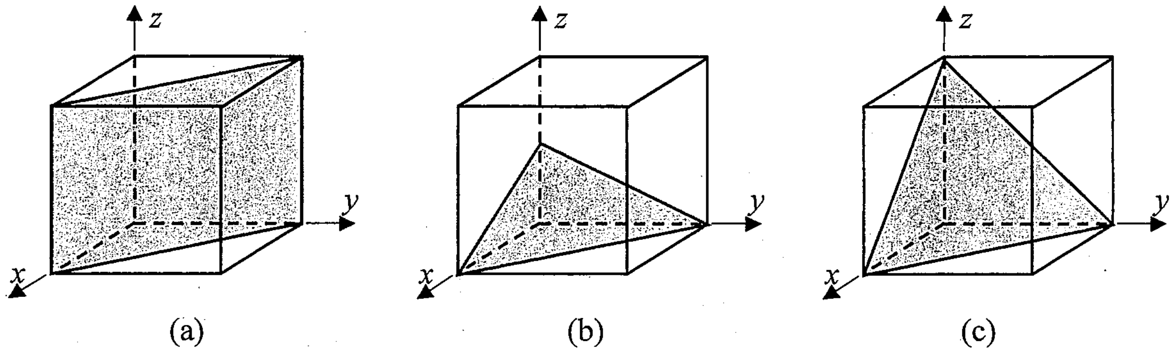

Fig. 1

(2) Explain the brittle fracture and ductile fracture of metals, respectively.

(3) Referring to the Fe-Fe_3C phase diagram in Fig. 2, draw schematic diagrams of the microstructures formed under the following conditions and explain the characteristics of the microstructures using the schematic diagrams, respectively.

a) Keeping Fe-2.0mass%C alloy at 750°C for a sufficiently long time.

b) Water-quenching Fe-0.5mass%C alloy from 1000°C.

c) Keeping Fe-0.1mass%C alloy at 750°C for a sufficiently long time.

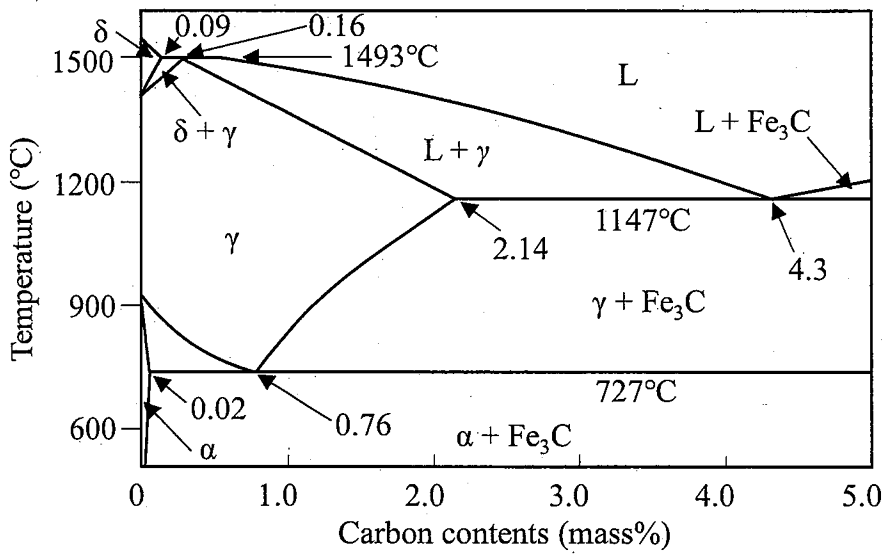

Fig. 2

(4) Hydrogen was introduced into the surface of a pure iron plate at 500°C, and then the concentration of hydrogen in the plate reached a steady state. Determine the hydrogen flux in the plate under steady state condition at 500°C, where the diffusivity of hydrogen in the pure iron at 500°C is 2.0×10^{-8} $m^2 s^{-1}$, the concentration of hydrogen at the front surface of the plate is 0.11 kg m^{-3}, the concentration of hydrogen at the back surface of the plate is 0.01 kg m^{-3}, and the thickness of the plate is 0.01 m.

化学基礎 CHEMISTRY BASICS

Ozone (O_3) reacts with nitrogen monoxide (NO) to form nitrogen dioxide (NO_2). Experiments on this reaction were conducted at 25.0°C under five different conditions, and the following data were obtained. Answer the following questions regarding this experiment, and NO and O_3.

	[NO] (mol L^{-1})	[O_3] (mol L^{-1})	$d[NO_2]/dt$ (mol L^{-1} s^{-1})
1	1.00×10^{-6}	3.00×10^{-6}	6.60×10^{-5}
2	1.00×10^{-6}	6.00×10^{-6}	1.32×10^{-4}
3	1.00×10^{-6}	9.00×10^{-6}	1.98×10^{-4}
4	2.00×10^{-6}	9.00×10^{-6}	3.96×10^{-4}
5	3.00×10^{-6}	9.00×10^{-6}	5.94×10^{-4}

(1) Show the dominant chemical reaction equation in the experiment.

(2) Show $d[NO_2]/dt$ as a function of [NO], [O_3], and the reaction rate constant k.

(3) Show the value and unit of the rate constant k for the reaction in question (2).

(4) Assume that the activation energy of this reaction is 2.50 kJ mol^{-1}. Using the values obtained in question (2), find the frequency factor in the Arrhenius equation. If necessary, use the gas constant R = 8.31 J K^{-1} mol^{-1} and Napier's constant e = 2.72.

(5) The property of O_3 to absorb ultraviolet rays can be used to measure O_3 concentration. Show an equation showing the relation of the absorbance A, l, and c, where l is the length of the optical path of the sample gas and c is the O_3 concentration. If necessary, define and use other symbols representing material properties. In addition, write an equation showing the relationship between the transmittance T and absorbance A.

(6) Show the electron dot structure (Lewis structure) and structural formula of NO.

(7) Write a half-reaction equation for O_3 as an oxidant to water.

放射化学　RADIOCHEMISTRY

Answer the following questions. In these questions, $\log_e 2 = 0.70$, and Avogadro's constant is 6.0×10^{23} mol^{-1}. The significant figure is two digits.

(1) A radioactive nuclide ${}^{A}_{Z}E$ decays by alpha decay with a half-life of t [s] to another radioactive nuclide E' that has the half-life of $0.1\times\ t$ [s]. Now, m [g] of the nuclide E is in radioactive equilibrium with the daughter nuclide E'.

a) Show the activity [Bq] of nuclide E.

b) Show the atomic number, the mass number, and the activity [Bq] of nuclide E'.

(2) A quantity of ion X^+ in solution-A was determined. First, 0.10 g of the radioactive tracer ${}^{mm}X^+$ (half-life: 2.0 hours, specific activity: 500 Bq/g) was added to solution-A, then it was completely mixed. 6.0 hours after the mixing, a portion of ion X^+ was extracted from the solution, then the specific activity of ion X^+ was determined to be 2.5 Bq/g. Answer the quantity [g] of ion X^+ originally in solution-A.

(3) The gamma rays of 0.733 MeV and 1.510 MeV emitted from ${}^{92}Tc$ in a sample are measured by a germanium semiconductor detector. The emission probabilities of these gamma rays are both 100 %. The peak counting efficiencies for the gamma rays of 0.733 MeV and 1.510 MeV by the detector are 12 % and 8.0 %, respectively. Answer the counting efficiency [%] for ${}^{92}Tc$ in the sample.

(4) A quantity of ${}^{90}Sr$ in seawater is determined by a radiation measurement. The half-lives of ${}^{90}Sr$ and its daughter nuclide are 29 years and 64 hours, respectively.

a) Show a radiation detector that is usable for this measurement.

b) Show a pre-treatment procedure for determining the quantity of ${}^{90}Sr$ using the detector you answered in a). Furthermore, answer the minimum time that is required for the completion of the pre-treatment after the sampling.

放射線工学
RADIATION ENGINEERING

Answer the following questions.

(1) Calculate the theoretical energy resolution of a detector for 60 keV gamma ray when the W value and Fano factor of the detector is 3.0 eV and 0.080, respectively. Here, the full width at half maximum of Gaussian distribution is 2.4 times of the standard deviation.

(2) Fig.1 shows a relationship between photon energy and mass attenuation coefficient of Germanium.

a) Significant change in mass attenuation coefficient is observed around photon energy of E_1. Explain the reason of the significant change.

b) An energy spectrum for photons (photon energy: E_2) was obtained using a Germanium detector. In the spectrum, besides the total absorption peak, two peaks were observed. Explain the reason why the two peaks appeared, assuming that all the electrons and X-rays induced by the incident photons are absorbed inside of the detector.

(3) Alpha particles of 5.0 MeV were uniformly absorbed in a human liver with a mass of 1.0 kg. Find the effective dose [mSv] when the number of absorbed alpha particles was 1.0×10^{10}. Here, the tissue-weighting factor of liver is 0.04, the radiation-weighting factor of alpha particle is 20 and 1 eV is 1.6×10^{-19} J. Neglect both other radiations and effect of alpha particles to other organs/tissues.

(4) Calculate the radioactivity [Bq] of ^{87}Rb within a human (body weight is 70 kg and 0.32 g of Rb is included in the body). Here, assume that the atomic weight of Rb is 86, the isotopic abundance of ^{87}Rb is 28%, the physical half-life of ^{87}Rb is 5.0×10^{10} year and $\log_e 2$ is 0.69.

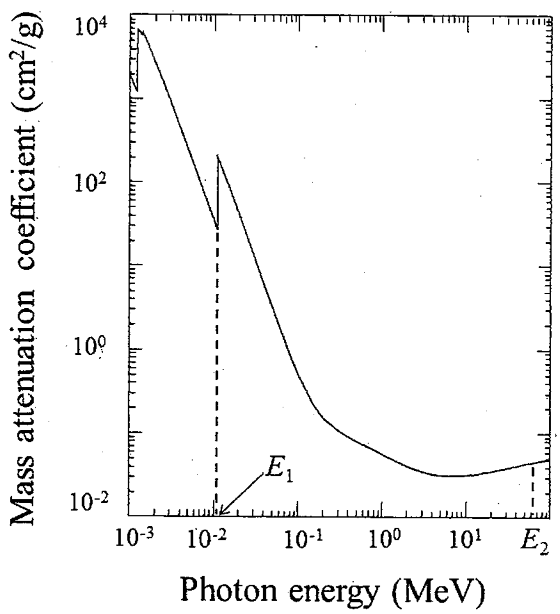

Fig.1

原子炉物理学　REACTOR PHYSICS

Answer the following questions.

(1) Choose three terms related with the reactor physics among the following ①−⑤, and briefly explain each of them. <u>Note that answering more than three terms makes all of your answers to this question invalid</u>.

① delayed neutron
② 1 dollar
③ diffusion approximation
④ macroscopic cross-section of absorption
⑤ void coefficient

(2) Chicago Pile-1, the world's first artificial nuclear reactor, consisted of graphite moderators and natural uranium fuels. In contrast, presently Japanese commercial nuclear reactors use not graphite but light water as a moderator. Answer the following questions.

a) Explain the neutronic characteristics of graphite that enabled Chicago Pile-1 to realize the criticality using not enriched uranium but natural uranium.

b) List two advantages of light water over graphite as a moderator.

(3) Consider a bare reactor in the shape of a slab of width a in the x-direction and infinite in the y- and z-directions. Obtain the critical condition and power peaking factor of the reactor when the reactor equation in the reactor is given as

$$\frac{d^2\phi}{dx^2} + B^2\phi = 0,$$

where ϕ and B are neutron flux and a constant, respectively. The boundaries of the reactor correspond to $x = \pm a/2$. Ignore extrapolation distance.