令 和 2 年 度 特 色 入 試 問 題

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小 論 文 試 験

250 点 満 点

（注　意）

1. 問題冊子および解答冊子は係員の指示があるまで開かないこと。
2. 問題冊子は表紙のほかに 8 ページある。
3. 解答冊子は問題ごとに 1 冊ずつある（全部で 3 冊ある）。
   それぞれの解答冊子は表紙のほかに各 6 ページある。
4. 試験開始後，解答冊子の表紙所定欄に受験番号・氏名をはっきり記入すること。
   表紙には，これら以外のことを書いてはならない。
5. 解答はすべて解答冊子の指定された箇所に記入すること。
6. 解答に関係のないことを書いた答案は無効にすることがある。
7. 解答冊子は，どのページも切り離してはならない。
8. 問題冊子は持ち帰ること。解答冊子は持ち帰ってはならない。
9. 解答は日本語で記入すること。

問題１　次の英文を読んで問1と問2に答えなさい．（80 点）

Eugene Hilgard first identified the growing problem of drainage and alkaline soils in the San Joaquin Valley around 1877. He concluded in 1889 that subsurface drainage was needed for waterlogged, saline, and sodic soils. W.W. Mackie in 1905 first investigated land reclamation with an experimental tile-drainage system at Kearney Park, near Fresno, in the San Joaquin Valley. Tile-drainage systems were installed beginning in the early 1950s in the west side of the San Joaquin Valley.

Since irrigation began about 1850, surface and subsurface drainage waters have been discharged into the San Joaquin River system. Federal and state agencies envisioned a 450-km master drain to serve the west side of the valley. However, by 1975, the U.S. Bureau of Reclamation had built only the upper 137-km reach of the San Luis Drain, terminating at Kesterson Reservoir, a flow-regulating reservoir in the master drain plan. Restrictions in the federal budget due to the Vietnam War delayed completion of the lower reaches of the drain. In 1979, the San Joaquin Valley Drainage Program recommended that the master drain be completed; however, in 1981, uncertainties about the potential environmental and health effects of the discharge of San Luis Drain into the Sacramento-San Joaquin Delta and the San Francisco Bay halted further construction.

Meanwhile, the San Luis Drain conveyed saline subsurface drainage waters from a 17,000-ha area affected by drainage to Kesterson Reservoir, which served as a terminal evaporation pond. From about 1981 to 1986, the average annual flow of tile effluents into the San Luis Drain was about 85,200 ha-cm, collected from about 2,000 ha of tile-drained fields and 1,200 ha drained by the open-joint collector system.

In 1982, selenium toxicity of fish and, in 1983, deformed and dead waterfowl were found in the Kesterson Reservoir. The selenium, averaging 300 μg/l (ppb) in the drain water, came from the Moreno shale, a geologic formation in the Coast Range Mountains that contributed the parent material for some of the soils formed in the west side of the San Joaquin Valley. The discovery of selenium toxicosis of waterfowl at Kesterson Reservoir and the presence of selenium in irrigation return flows in the western United States emphasized the need for agriculture to be concerned about edge-of-field effects on the environment. Discharge of the effluents into the San Luis Drain was halted in June 1986.

Massive state and federal investigations have been underway since 1985 on how to contain and dissipate selenium in the Kesterson Reservoir and develop management options to mitigate drainage problems in the San Joaquin Valley. An irrigation-drainage study in seven Western states where selenium toxicity is suspected has been underway since 1986. The San Joaquin Valley Drainage Program drafted planning alternatives to solve agricultural drainage and drainage-related problems in the San Joaquin Valley. This program's goals are to minimize potential health risks, protect reasonable and beneficial uses of waters, sustain productivity of farmlands, and protect and restore fish and wildlife.

・・・(中略)・・・

A consensus exists among all interested parties that source control for subsurface drainage, salinity, and selenium is the most important option. Some potential exists for the reuse of drainage water. Various drainage water treatment processes to remove selenium are available, but they are too expensive for agriculture to bear the entire cost. Limited potential exists for drainage-water disposal in the San Joaquin River, but not all drainage districts have a drainage outlet to the river. Evaporation ponds are currently being used, but some appear to be producing symptoms of toxicity in waterfowl. Nonagricultural sectors of society strongly support the use of fresh water for fish and wildlife. Some of the proposed institutional changes and other technical options will be needed to solve the drainage problem. Drainage-water disposal through a master drain into the San Francisco Bay Delta system or into the Pacific Ocean is not being considered by the San Joaquin Valley Drainage Program because it is perceived as politically infeasible.

・・・(中略)・・・

In semiarid to arid climates, irrigated agriculture requires leaching and drainage. In the past, it was assumed that residuals from agriculture, especially saline drainage waters, would be disposed of somewhere, somehow. Now other water users have demanded that agriculture minimize the degradation of water quality. Federal, state, and local regulations on nonpoint sources of pollutants are being promulgated.

Irrigated agriculture needs to strive for a balance between maintaining agricultural productivity and protecting our natural resources.

(出典：Kenneth K. Tanji (1990). Nature and extent of agricultural salinity. In Kenneth K. Tanji (Ed.), *Agricultural Salinity Assessment and Management*. American Society of Civil Engineers を一部改変)

（語注）subsurface : 地下，waterlogged : 水分を多く含む，saline : 塩水性の，sodic : ナトリウムを含む，land reclamation : 土地造成，tile-drainage : 暗渠排水（地下に設置したパイプによる排水），irrigation : 灌漑，envision : 構想する，terminate : 終わらせる，flow-regulating : 流量調整，reservoir : 貯水池，meanwhile : 同時に，evaporation pond : 蒸発池（池内での蒸発により減量される），effluent : 排水，selenium : セレン，toxicity : 毒性，deform : 奇形にする，waterfowl : 水鳥，shale : 頁岩，geologic formation : 地層，parent material : 母材，toxicosis : 中毒，irrigation return flow : 灌漑のための反復水（排水の再利用），underway : 進行中，dissipate : 消散する，mitigate : 軽減する，salinity : 塩分，infeasible : 実現不可能，semiarid : 半乾燥，leaching : 溶脱（下方浸透により物質を洗い流すこと），residual : 残り物，degradation : 悪化，nonpoint source : 面源（農地，市街地などの面的に広がった汚染源），pollutant : 汚染物質，promulgate : 公布する，strive : 努力する

問１　カリフォルニア州 San Joaquin Valley での農業排水に関わる問題とその対処について，1850 年頃から 1986 年までの変遷を，本文の第 1～4 段落の内容に基づいて，350～400 字で説明しなさい．

問２　本文の第 5 段落以降の内容に基づいて，農業排水の問題解決において考慮すべき視点を説明するとともに，文章中に述べられているいくつかの具体的な解決方法から 3 つを挙げなさい．

このページは白紙である

問題２　以下の文章を読んで，**問い**に答えなさい．(90 点)

水平な面の上で同じ質量，同じ円形状，同じ材質の 2 つのコイン A と B を離れた位置に置いた．はじめコイン A と B は静止状態であったが，コイン A に初速度を与え，コイン B に衝突させた．何度かこの実験を繰り返し，2 つのコインの最初の位置と，衝突後に静止した位置を記録した．ただし，明らかに衝突が激しく，コインが水平な面から離れて浮き上がったものや，コインが回転してしまったもの，コインの速度が小さいと思われたものは除外した．

図 1 は，これらの実験のうちの 1 つを図示したものである．はじめのコイン A と B の位置は図中に示す A_0 と B_0 の位置であった．この例ではコイン A の進行方向の延長線上にコイン B の中心がなかったため，衝突後，コイン A が右へ長さ l_A，コイン B が左へ長さ l_B だけ動いて，それぞれ A_2，B_1 の位置で止まった．なお衝突直前のコイン A の位置を A_1 とする．

面上に記録された結果から，**図 2** に示すように，ベクトル$\overrightarrow{A_1A_2}$とベクトル$\overrightarrow{B_0B_1}$の合成ベクトルの方向は，ベクトル$\overrightarrow{A_0A_1}$の方向とは一致しなかった．しかし，結果の検討と試行錯誤を重ねるうちに，**図 3** に示すように，方向が$\overrightarrow{A_1A_2}$と同じで長さが$\sqrt{l_A}$のベクトルと，方向が$\overrightarrow{B_0B_1}$と同じで長さが$\sqrt{l_B}$のベクトルの合成ベクトルの方向は，$\overrightarrow{A_0A_1}$と非常に近いものとなることがわかった．**図 3** では，見やすいようにそれぞれのベクトルを k 倍して作図した．**図 1** に示した例以外の実験においても同様の結果が得られた．以上のことから次の仮説を設定した．

仮説：2 つのコインについて，衝突後の移動方向を向きとし，長さを移動距離の平方根とする 2 つのベクトルを考える．この 2 つのベクトルの合成ベクトルの方向は，A の衝突前の移動方向と同じである．ただし仮定として 2 つのコインのはねかえり係数 e を $e=1$ とみなした．また，面とコインの間の動摩擦係数は一定であったと仮定した．

問い　以下の a)から c)の内容を織り込みながら，上記の仮説は，どのような物理法則を作図によって推定したものとなっているかを説明しなさい．

a) **図 2** に示す角度αとβの関係．
b) コインの衝突直後の速度，面とコインの間の動摩擦係数，衝突後の移動距離の関係．
c) 実験において，仮説で示した方向の一致が正確には得られなかった原因．

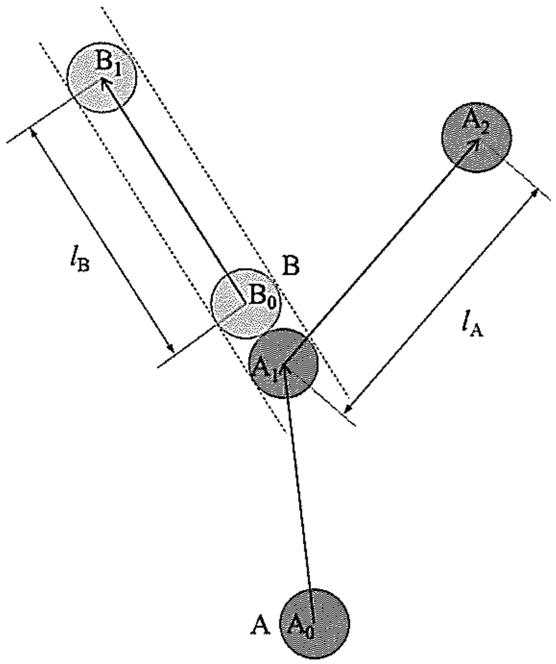
B
B_1
B_0
A_1
A_2
l_B
l_A
A
A_0

図 1

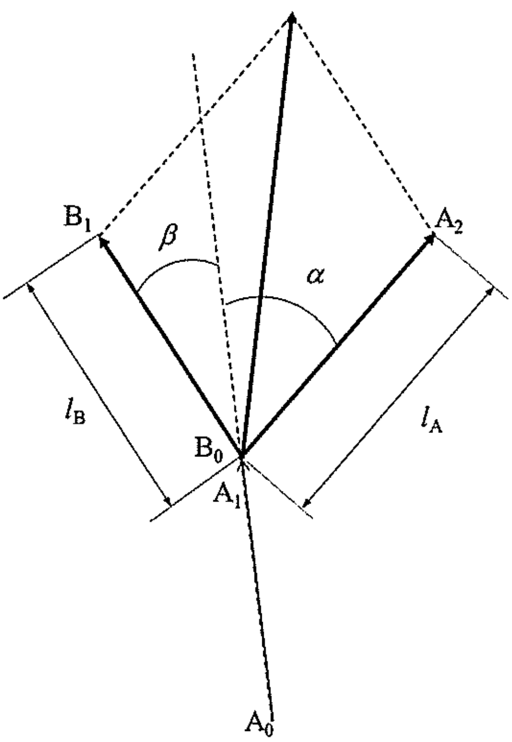
B_1
β
α
A_2
l_B
l_A
B_0
A_1
A_0

図 2

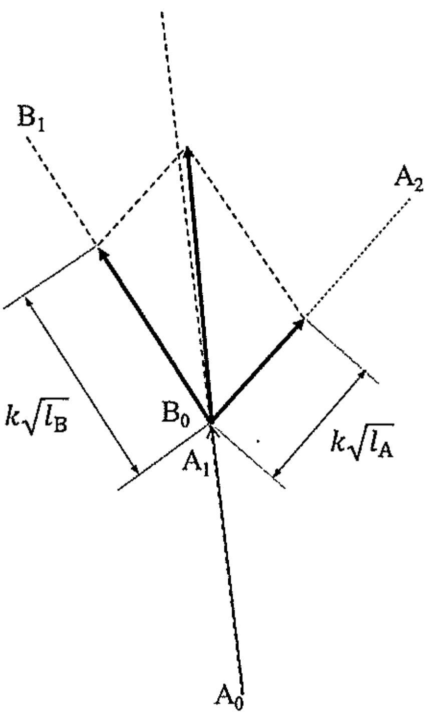
B_1
A_2
$k\sqrt{l_B}$
B_0
$k\sqrt{l_A}$
A_1
A_0

図 3

問題3　以下の英文を読んで問1と問2に答えなさい．（80 点）

To understand how a turbine extracts energy from the wind, imagine air entering the input port of the turbine (with area A) at speed v_i, then encountering fan blades at the reduced speed $v_f < v_i$ (and so exerting a force on the blades, which rotate the shaft of an electric generator), and then finally exiting the output port of the turbine (with area A) at the further reduced speed $v_o < v_f$. The force exerted on the fan blades is the *rate of change* of the moving air's momentum, from when it enters until it leaves the turbine.

If we write ρ as the density of air (in units of kilograms/cubic meter), then the rate at which air mass (kilograms/second) passes through the fan blades is

$$\mu = \rho A v_f,$$

which you can confirm has the units of kilograms/second. This is called the *air flux*. As the air flux enters the input port it carries momentum at the *rate* of μv_i, and as the flux exits the output port it carries momentum at the *rate* of μv_o. Again, you should confirm that μv has the units of momentum per unit time (kilograms·meters/seconds-squared), that is, of force.

Thus, the force on the blades is

$$F = \mu v_i - \mu v_o = \mu(v_i - v_o).$$

Since power is force times speed, the fan power P_f is

$$P_f = F v_f = \mu(v_i - v_o)v_f = \rho A v_f (v_i - v_o) v_f,$$

or

$$P_f = \rho A v_f^2 (v_i - v_o).$$

The fan power can also be expressed as the difference between the *rate* at which kinetic energy enters the input port and the *rate* at which kinetic energy exits the output port, and so

$$P_f = \frac{1}{2}\mu(v_i^2 - v_o^2) = \frac{1}{2}\rho A v_f (v_i^2 - v_o^2).$$

Equating our two expressions for P_f, we have

$$\rho A v_f^2 (v_i - v_o) = \frac{1}{2}\rho A v_f (v_i^2 - v_o^2),$$

or

$$v_f = \boxed{\quad (A) \quad}\ .$$

Substituting this expression for v_f into either expression (in this case, the first one) for the fan power, we have

$$P_f = \boxed{\quad (B) \quad}\ .$$

All the parameters on the right-hand side are either fixed (ρ and A) or out of our control

(v_i). We can, however, control v_o, the ouput air speed, with suitable mechanical design of the turbine.

To maximize P_f, we set the derivative of P_f (with respect to v_o) equal to zero:

$$\frac{dP_f}{dv_0} = \boxed{\quad (C) \quad} = 0$$

or, at last,

$$v_o = \boxed{\quad (D) \quad} v_i.$$

For maximum fan power the air speed at the exit port should be $\boxed{\quad (D) \quad}$ of the input port air speed. Under this condition the maximum fan power, $P_{f\max}$, is given by

$$P_{f\max} = \boxed{\quad (E) \quad}.$$

Now, since $P_{\text{input}} = \frac{1}{2}\rho A v_i^3$ is the power level at the input port, then

$$\frac{P_{f\max}}{P_{\text{input}}} = \boxed{\quad (F) \quad},$$

a value called the <u>*Betz limit*</u>.

(出典：Paul J. Nahin (2016). *In Praise of Simple Physics: The Science and Mathematics behind Everyday Questions*. Princeton University Press を一部改変)

問1　(A) から (F) に入る式または値を答えなさい.

問2　この文章で求めた *"Betz limit"* とは何か説明しなさい.