ENGR 356 – FLUID MECHANICS – SECTION 1 – SPRING 2018

QUIZ I

Please read the following information closely.

- You have **75 minutes** from the moment that the beginning of the quiz is announced.

- This exam consists of two problems. Each is worth up to six credits, out of 100 credits for the whole course. At most six credits can be gained from the present term exam.

  You need to **work on one or two problems** to achieve an optimal outcome.

- If you **choose to work on a single problem**, only the credits for this problem will count, yielding an optimum total of six credits. If you **choose to work on both problems**, only the problem with the best grade will count, again yielding an optimum total of six credits. Appealing to the head of department, board of trustees, etc., will not change any grades.

- There will be another unannounced quiz in the course of the semester, yielding up to six credits also. However, the **total from both quizzes** is capped at a **maximum of ten credits**.

Partial results give partial credits – write what you know, even if your solution is incomplete.

If you need less than 75 minutes, feel free to hand in your results at any time and leave the room quietly without disturbing the other participants. Any discussion with other students and any access to means of communication is a case of cheating irrespective of what is communicated.

In your own interest, please avoid unnecessarily long answers.

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Full name: ___________________________________

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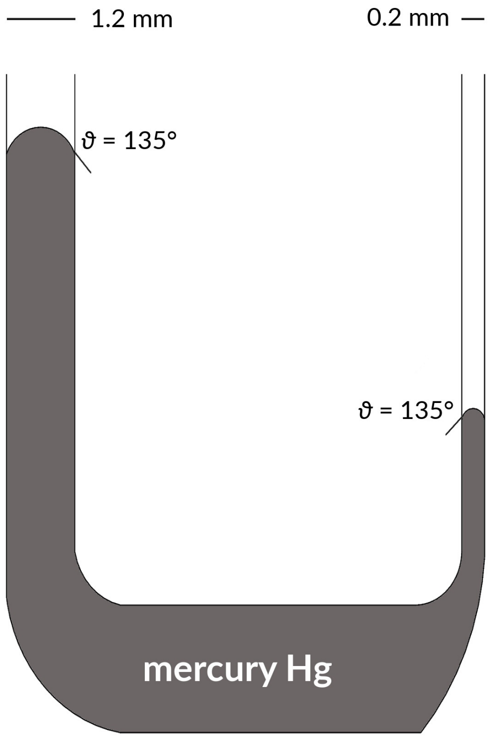
PROBLEM 1

Two microscopic cylindrical capillaries, with diameters of 1.2 mm and 0.2 mm, respectively, are connected in a U-shaped glass construction as illustrated, which has been partially filled with liquid mercury. The capillaries are open to the air, which is at ambient pressure.



Mercury does not wet the glass surface. The glass acts as a solvophobic material: Partial dewetting is found, and the contact angle is $\vartheta = 135°$. The Young equation, $\cos\vartheta = (\gamma_{vs} - \gamma_{ls}) / \gamma_{vl}$, relates the contact angle to the vapor-solid (vs), liquid-solid (ls), and vapor-liquid (vl) surface tensions. The pressure difference at a spherical interface is given by the Laplace equation $\Delta p = 2\gamma/r$, where r is the radius of curvature of the interface, which for capillary depression in a cylindrical capillary is related by $R = r\,|\cos\vartheta|$ to the capillary radius R.

Gravity $\mathbf{g}$, with $g_x = g_y = 0$ and $g_z = -9.807$ ms^{-2}, induces a pressure gradient $\nabla p = \rho\mathbf{g}$. Assume liquid mercury to be incompressible with the density $\rho = 13\,550$ kg m^{-3}. The mercury-air surface tension is $\gamma_{vl} = 0.485$ N m^{-1}.

Determine the deviation Δz between the mercury (surface) levels in the two capillaries.

PROBLEM 2

In the sea, gravity $\mathbf{g}$, with $g_x = g_y = 0$ and $g_z = -9.807$ ms^{-2}, induces a pressure gradient $\nabla p = \rho\mathbf{g}$ as described by the basic equation of fluid statics. Define the altitude $z = 0$ to be at sea (surface) level, and neglect temperature gradients in the water; assume that $T = 280$ K, and assume water to be compressible with a constant isothermal compressibility of $\beta_T = (\partial \ln\rho / \partial p)_T = 0.4689$ GPa^{-1}.

Accordingly, the pressure-density relationship is approximated by $\ln(\rho/\rho_0) = \beta_T(p - p_0)$, where β_T is the isothermal compressibility as given above, $p_0 = 101.3$ kPa is the atmospheric pressure at sea level, and $\rho_0 = 999.9$ kg m^{-3} is the density of liquid water at $T = 280$ K and the pressure p_0.

Determine the pressure 4 km below sea level, i.e., at altitude z = −4000 m, up to four significant digits.

Suggestion: With $p^{\text{gage}} = p - p_0$, deduce an expression for z as a function of p^{gage}, then resolve to p.

$$\int_0^x \exp(ax)\,dx = \frac{1}{a}\left[\exp(ax) - 1\right]$$

In your own interest, please avoid unnecessarily long answers.

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