Name: **ID:**

Midterm #1 - P3A - Version A

Prof. Laszlo Bardoczi, September 16, 2025

- The exam is 40 minutes long and contains 4 calculation problems.
- You must solve 3 problems of your choice; 1 problem will not be graded.
- Each problem is worth up to 3 points (parts a, b & c): 0.5 point for a correct numerical value (to 2 significant figures); 0.5 point for correct SI units. Partial credit is awarded based solely on the boxed answers.
- Write final answers clearly in the designated boxes. Leave the boxes empty for the problem you do not wish to be graded. If all boxes are filled, Problem #4 will not be graded.
- A detachable formula sheet is provided at the end of the exam.
- At the end of the exam, submit only the front page and present your UCI ID for verification.
- Direct all grading questions to your TA.
- Cheating will result in an automatic failing grade for the course.

1. (a)	**1. (b)**	**1. (c)**
2. (a)	**2. (b)**	**2. (c)**
3. (a)	**3. (b)**	**3. (c)**
4. (a)	**4. (b)**	**4. (c)**

Problem 1: Diffusion

Ciprofloxacin is an antibiotic that blocks bacterial DNA replication by binding enzymes in the nucleoid. After crossing the cell membrane, the drug must diffuse through the cytoplasm to reach the DNA. Assume the following: (1) effective step size of diffusion in cytoplasm: $d = 0.4\,\mathrm{nm}$ (2) step (collision) time: $\tau = 2.0 \times 10^{-8}\,\mathrm{s}$, (3) motion occurs in 3 dimensions ($m = 3$) and (4) distance to DNA (half the bacterial diameter) is $r_{\mathrm{rms}} = 0.8\,\mu\mathrm{m}$.

(a) Estimate the number of steps n required for a ciprofloxacin molecule to diffuse from the membrane to the DNA.

(b) Calculate the total diffusion time for $r_{\mathrm{rms}} = 0.8\,\mu\mathrm{m}$.

(c) What would be the diffusion time on the scale of an organ? (repeat (b) for $r_{\mathrm{rms}} = 5\,\mathrm{cm}$) Give the answer in terms of years.

Solution

The root-mean-square displacement in m dimensions is

$$r_{\mathrm{rms}} = d\sqrt{mn}.$$

(a) Number of steps n:

$$n = \frac{r_{\mathrm{rms}}^2}{md^2}.$$

Plugging in numbers:

$$n = \frac{(0.8 \times 10^{-6})^2}{3(0.4 \times 10^{-9})^2} = \frac{0.64 \times 10^{-12}}{0.48 \times 10^{-18}} \approx 1.3 \times 10^6.$$

(b) Total diffusion time:

$$t = n\tau = (1.3 \times 10^6)(2.0 \times 10^{-8}\,\mathrm{s}) = 2.6 \times 10^{-2}\,\mathrm{s}.$$

So the antibiotic reaches the DNA in about 26 ms.

(c) Diffusion time across an organ ($r_{\mathrm{rms}} = 0.050\,\mathrm{m}$):

$$n = \frac{(0.050)^2}{3(0.4 \times 10^{-9})^2} = \frac{0.0025}{0.48 \times 10^{-18}} \approx 5.2 \times 10^{15}.$$

$$t = n\tau = (5.2 \times 10^{15})(2.0 \times 10^{-8}\,\mathrm{s}) = 1.0 \times 10^8\,\mathrm{s}.$$

Converting to years:

$$t = \frac{1.0 \times 10^8}{60 \times 60 \times 24 \times 365} \approx 3.2\,\mathrm{years}.$$

Final Answers:

(a) $\boxed{n \approx 1.3 \times 10^6}$, (b) $\boxed{t \approx 2.6 \times 10^{-2}\,\mathrm{s}\ (26\,\mathrm{ms})}$, (c) $\boxed{t \approx 1.0 \times 10^8\,\mathrm{s}\ (\sim 3.2\,\mathrm{years})}$

Problem 2: Proportional Reasoning

The volume of air in your lungs changes as you breathe, but a typical value at mid-breath is about $1\,\mathrm{L} = 1000\,\mathrm{cm}^3$.

(a) Model the lungs as two identical spheres. Approximately what is the diameter of a lung?

(b) What would be the total lung surface area under this spherical model?

(c) In reality, the total lung surface area is approximately $70\,\mathrm{m}^2$ because the lungs are not empty spheres but are subdivided into about 300 million alveoli, small sacs through which gases diffuse into and out of capillaries. Assuming alveoli are spherical and together make up the $70\,\mathrm{m}^2$ surface area, approximately what is the diameter (in μm) of an alveolus?

Solution

(a) The volume of both lungs is $1000\,\mathrm{cm}^3 = 1000 \times 10^{-6}\,\mathrm{m}^3 = 1.0 \times 10^{-3}\,\mathrm{m}^3$. So one lung has half this volume:

$$V = 5.0 \times 10^{-4}\,\mathrm{m}^3.$$

For a sphere, $V = \frac{4}{3}\pi r^3$. Solving for r:

$$r = \left(\frac{3V}{4\pi}\right)^{1/3} = \left(\frac{3(5.0 \times 10^{-4})}{4\pi}\right)^{1/3} \approx 0.049\,\mathrm{m} \quad \Rightarrow \quad \text{diameter} \approx 0.098\,\mathrm{m} \approx 9.8\,\mathrm{cm}.$$

(b) Surface area of one lung: $A = 4\pi r^2 = 4\pi(0.049)^2 \approx 0.030\,\mathrm{m}^2$. For both lungs: $A_{\text{total}} \approx 0.060\,\mathrm{m}^2$.

(c) Real lung surface area is $70\,\mathrm{m}^2$, divided among about 3.0×10^8 alveoli. Average surface area per alveolus:

$$A_{\text{alveolus}} = \frac{70}{3.0 \times 10^8} \approx 2.33 \times 10^{-7}\,\mathrm{m}^2.$$

For a sphere, $A = 4\pi r^2$. Solving for r:

$$r = \sqrt{\frac{A}{4\pi}} = \sqrt{\frac{2.33 \times 10^{-7}}{4\pi}} \approx 1.36 \times 10^{-4}\,\mathrm{m}.$$

Diameter:

$$d = 2r \approx 2.7 \times 10^{-4}\,\mathrm{m} = 270\,\mu\mathrm{m}.$$

Final Answers:

$$\text{(a)}\ \boxed{\approx 9.8\,\mathrm{cm}}, \quad \text{(b)}\ \boxed{\approx 0.060\,\mathrm{m}^2}, \quad \text{(c)}\ \boxed{\approx 270\,\mu\mathrm{m}}$$

Problem 3: Motion Along a Line

While running a marathon, a long-distance runner times 100 m in 18 s. Using ratios (without computing velocity):

(a) How long will it take her to run the next 400 m?

(b) How long will it take her to run 1 mile at this speed?

(c) If she ran for 30 min at this speed, what speed must she run for the next 30 min so that her average speed over the full hour is 7.0 m/s?

Solution

We use proportionality for constant speed:

$$\frac{t_2}{t_1} = \frac{d_2}{d_1}, \quad d_1 = 100\,\mathrm{m}, \quad t_1 = 18\,\mathrm{s}.$$

(a) For 400 m**:**

$$t_{400} = \frac{400}{100} \times 18 = \boxed{72\,\mathrm{s}}.$$

(b) For 1 mile = 1609 m**:**

$$t_{\mathrm{mile}} = \frac{1609}{100} \times 18 \approx 289.6\,\mathrm{s} \approx \boxed{290\,\mathrm{s}}.$$

(c) Required speed for the second 30 min**:**
From part (a), her speed is

$$v_1 = \frac{100}{18} \approx 5.56\,\mathrm{m\,s^{-1}}.$$

Distance in the first 30 min:

$$d_1 = v_1 \times (30 \times 60) = 5.56 \times 1800 \approx 10\,000\,\mathrm{m}.$$

Total time = 3600 s. Target distance for average speed of $7.0\,\mathrm{m\,s^{-1}}$:

$$d_{\mathrm{target}} = 7.0 \times 3600 = 25\,200\,\mathrm{m}.$$

So distance needed in the second half:

$$d_2 = d_{\mathrm{target}} - d_1 = 25200 - 10000 = 15\,200\,\mathrm{m}.$$

Required speed for the second half:

$$v_2 = \frac{d_2}{1800} = \frac{15200}{1800} \approx \boxed{8.44\,\mathrm{m\,s^{-1}}}.$$

Final Answers:

$$\text{(a) } \boxed{72\,\mathrm{s}}, \quad \text{(b) } \boxed{290\,\mathrm{s}}, \quad \text{(c) } \boxed{8.44\,\mathrm{m\,s^{-1}}}$$

Problem 4: Motion in Gravity

A frog leaps horizontally while escaping a predator. Its jump covers a horizontal distance of 6.0 m and reaches a maximum vertical height of 1.5 m.

(a) What is the frog's speed just as it leaves the ground?

(b) At what angle above the horizontal does it take off?

(c) How long is the frog in the air?

Solution

We use projectile motion relations with:

$$R = 6.0\,\mathrm{m}, \quad h = 1.5\,\mathrm{m}, \quad g = 9.8\,\mathrm{m\,s^{-2}}.$$

(a) Initial speed v_0:
At maximum height:

$$h = \frac{v_y^2}{2g} \quad \Rightarrow \quad v_y = \sqrt{2gh}$$

$$v_y = \sqrt{2(9.8)(1.5)} \approx 5.42\,\mathrm{m\,s^{-1}}.$$

Time to reach max height:

$$t_{\mathrm{up}} = \frac{v_y}{g} = \frac{5.42}{9.8} \approx 0.55\,\mathrm{s}.$$

Total flight time:

$$T = 2t_{\mathrm{up}} \approx 1.10\,\mathrm{s}.$$

Horizontal velocity:

$$v_x = \frac{R}{T} = \frac{6.0}{1.10} \approx 5.45\,\mathrm{m\,s^{-1}}.$$

Initial speed:

$$v_0 = \sqrt{v_x^2 + v_y^2} = \sqrt{(5.45)^2 + (5.42)^2} \approx 7.7\,\mathrm{m\,s^{-1}}.$$

(b) Launch angle θ:

$$\theta = \arctan\left(\frac{v_y}{v_x}\right) = \arctan\left(\frac{5.42}{5.45}\right) \approx 45^\circ.$$

(c) Time of flight:

$$T \approx 1.10\,\mathrm{s}.$$

Final Answers:

$$\text{(a) } \boxed{v_0 \approx 7.7\,\mathrm{m\,s^{-1}}}, \quad \text{(b) } \boxed{\theta \approx 45^\circ}, \quad \text{(c) } \boxed{T \approx 1.1\,\mathrm{s}}$$

Physics 3A Formula Sheet