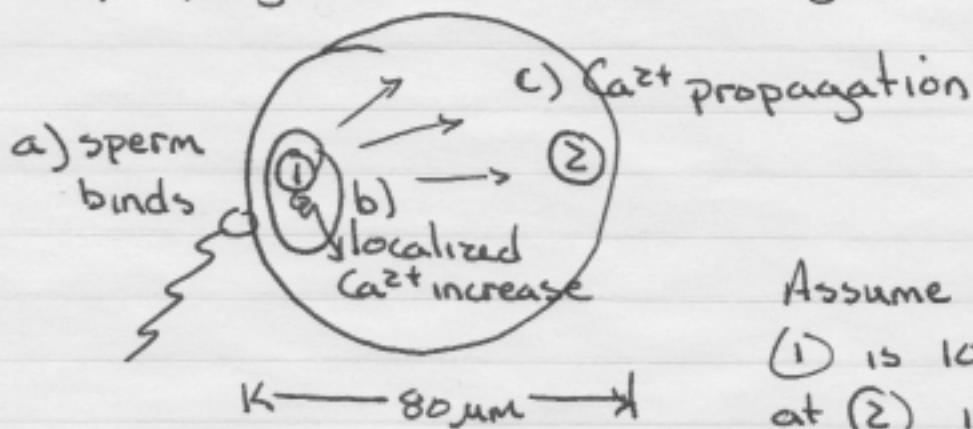


QUESTION ONE

When a sperm cell binds to an oocyte, it causes a localized cytoplasmic $[Ca^{2+}]$ increase, which then propagates across the oocyte



Assume $[Ca^{2+}]$ at (1) is $10\ \mu\text{M}$ and at (2) is $0.1\ \mu\text{M}$.

- A. What is the Ca^{2+} flux, $J_{Ca^{2+}}$, immediately after sperm binding from (1) to (2)?
- B. Ca^{2+} propagates across the cell in about 60 seconds. Can diffusion explain the propagation?

Assume the Ca^{2+} diffusion coefficient is $5.6\ \mu\text{m}^2\text{sec}^{-1}$

Equations you may need.

$$J = -D \frac{dc}{dx}$$

$$J = P(c_o - c_i)$$

$$L = \sqrt{6Dt}$$

distance diffusion coefficient time

$$\frac{dc}{dt} = D \frac{d^2c}{dx^2}$$

QUESTION TWO

A single glucose transporter can pass as many as 10^6 glucose molecules per second.

How many glucose transporters would be required to increase the permeability coefficient for glucose from

10^{-8} cm sec $^{-1}$ (lipid bilayer)
to
 10^{-4} cm sec $^{-1}$ (animal cell membrane)

Indicate clearly all assumptions.

Equations you may need

Sphere Area: $4\pi r^2$

Volume: $\frac{4}{3}\pi r^3$

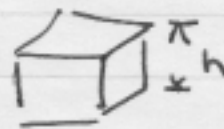
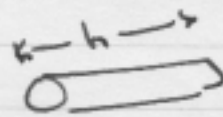
Cylinder Area: $2\pi r h$

Volume: $\pi r^2 h$

Cube
~~Square~~

Area: ~~6~~ $6h^2$

Volume: h^3



$$J = -P(c_o - c_i)$$

$$6.023 \times 10^{23} \text{ molecules/mole}$$

QUESTION THREE

Propose a role for cardiolipin in the inner membrane of the mitochondria, accounting for the effect it will have on bilayer structure compared to phosphatidylethanolamine and phosphatidylcholine.

Table 11-5 Polar head groups of the phosphoglycerides

The head alcohols are shown in color. The open bonds on the phosphoric residues are to position 3 of 1,2-diacylglycerol.

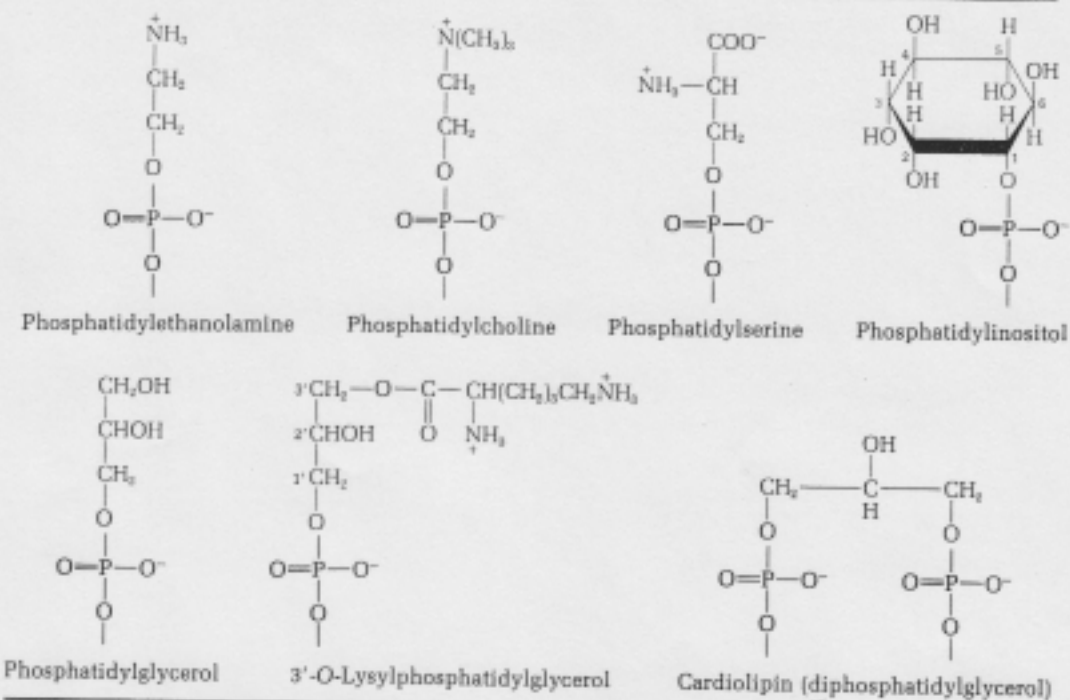
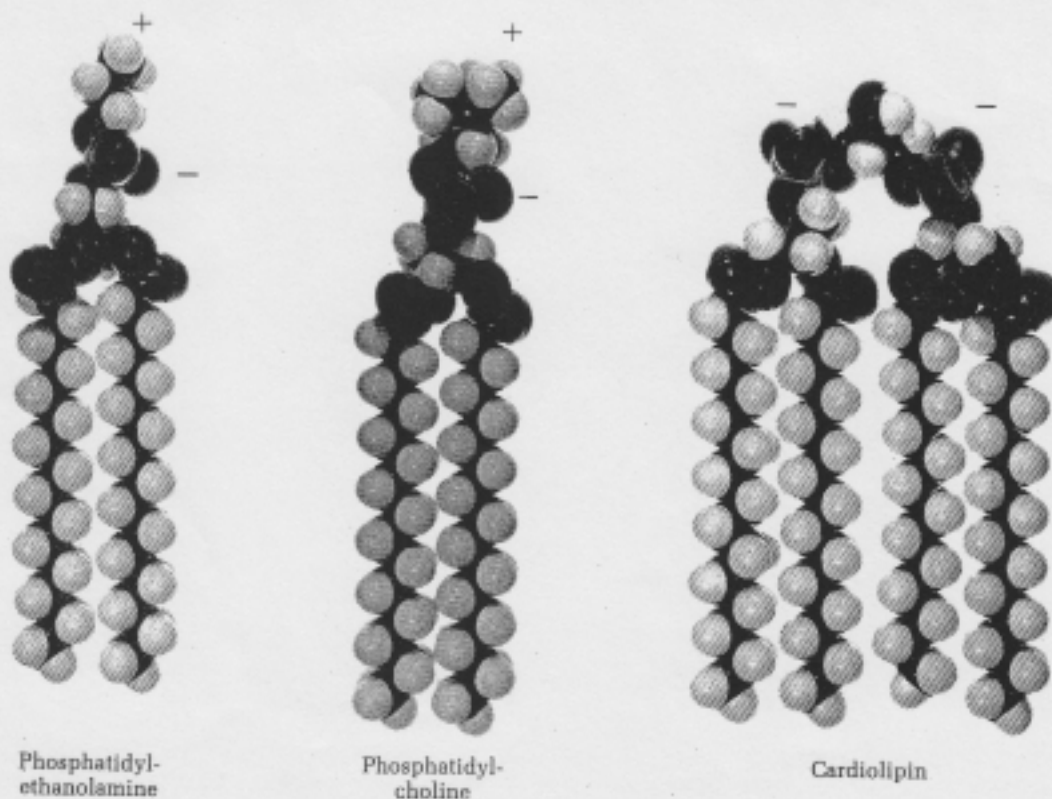


Figure 11-12
Space-filling models of three phosphoglycerides, showing location of the charged groups.



Question One

A. $\delta = -D \frac{dc}{dx}$ 6/10

partial credit $\delta = P(c_o - c_i)$ 4/10

evaluate $\frac{dc}{dx} = \frac{\Delta c}{d}$ 2/10

acknowledge $\frac{dc}{dx}$ not linear 2/10

B. $L = \sqrt{6Dt}$ 8/10

solving for t to compare to 60 sec. 2/10

Question Two

$n \cdot \delta = (P_2 - P_1)(\Delta C)$ 20/20

partial credit for "torques" work shown 12-16/20

Question Three

2 -ve charges proton wire 8/20

4 acyl chains $\frac{1}{2}$ fluidity 8/20

non-bilayer possibilities 4/20

/40

$$1 \times 10^{-3} \frac{\text{moles}}{10^3 \text{ cm}^3} \quad \frac{1}{\text{min. (time)}}$$

Volume of Cell

Radius 10 μm (10^{-3} cm)

$$\frac{4}{3} \pi r^3 \quad \left(\frac{4}{3}\right)(3.14)(10^{-3})^3 = 4.19 \times 10^{-9} \text{ cm}^3$$

moles/cell · (time)

$$10^{-6} \frac{\text{mole}}{\text{cm}^3} \cdot 4.19 \times 10^{-9} \frac{\text{cm}^3}{\text{cell}} = 4.19 \times 10^{-15} \frac{\text{mole}}{\text{cell}}$$

moles/area

$$\text{AREA } 4\pi r^2 = 1.257 \times 10^{-5} \text{ cm}^2.$$

$$4.19 \times 10^{-15} \frac{\text{mole}}{\text{cell}} \cdot \frac{\text{cell}}{1.257 \times 10^{-5} \text{ cm}^2}$$

$$= 3.33 \times 10^{-10} \frac{\text{mole}}{\text{cm}^2 \cdot \text{min}} = 5.556 \times 10^{-12} \frac{\text{mole}}{\text{cm}^2 \cdot \text{sec.}}$$

$$J = P(C_o - C_i) \quad \begin{array}{l} \text{Assume } 1 \text{ mm} \\ \uparrow \\ = 10^{-6} \frac{\text{mole}}{\text{cm}^3} \end{array}$$

$$\frac{J}{P} + C_i = C_o \quad \frac{5.556 \times 10^{-12} \frac{\text{mole}}{\text{cm}^2 \cdot \text{sec}}}{10^{-4} \text{ cm/sec}} + 10^{-6} \frac{\text{mole}}{\text{cm}^3}$$

$$\rightarrow 1.06 \times 10^{-6} \frac{\text{mole}}{\text{cm}^3}$$

(1.06 mm)

$$10^{-8} \text{ cm/sec} \quad 6 \times 10^{-4} \frac{\text{mole}}{\text{cm}^3}$$

(557 mm)

SECOND TERM TEST: Choose Two of the Three Questions

Question One

A. Propose the relative permeability and conductance of the gramicidin ion channel to divalent cations compared to sodium. Give a clear, diagrammatic explanation.

B. For an anion-selective channel, propose a mechanism that explains selectivity to anions compared to cations, and propose relative permeability and conductance compared to fluoride (F^-).

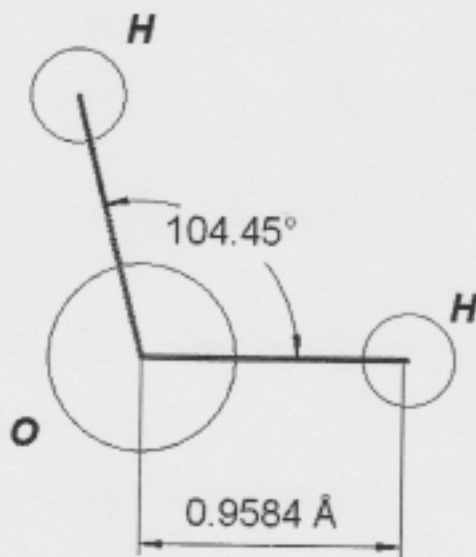
Ion Species	Ion Atomic Radius (Å)	ΔH° hydration (kcal/mole)	Mobility 10^{-4} (cm/sec)/(V/cm)
Tl^+	1.44	.	7.74
H^+	.	.	36.3
NH_4^+	1.48	.	7.52
Cs^+	1.69	-72	8.01
Rb^+	1.48	-79.2	8.06
K^+	1.33	-85.8	7.62
Na^+	0.95	-104.6	5.19
Li^+	0.6	-131.2	4.01
Cl^-	1.81	-82	7.92
F^-	1.36	114	5.74
Br^-	1.95	-79	8.09
I^-	2.16	-65	7.96
NO_3^-	2.9	.	7.41
Mg^{2+}	0.65	-476	2.75
Ca^{2+}	0.99	-397	3.08
Sr^{2+}	1.13	-362	3.08
Ba^{2+}	1.35	-328	3.3

Question Two

Capacitance plays a key role in constraining the number of Na^+ channels required to cause the depolarizing phase of an action potential in spherical cells of small size. Describe (diagrams may help) the effect of size and geometry (from spherical to a long, thin cable-like structure like an axon) on number of Na^+ channels required for the depolarizing phase of an action potential.

Question Three

Predict the size of an ion from its mobility and compare its predicted size to the size based on the molecular dimensions of the ion and surrounding water molecules (O-H bond lengths in H_2O are 0.96 \AA [0.096 nm]).



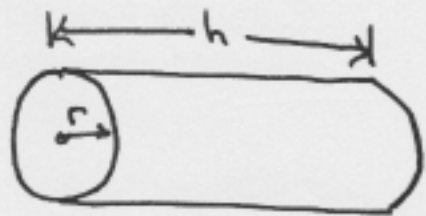
EQUATIONS

Sphere Area: $4\pi r^2$

Sphere Volume: $\frac{4}{3}\pi r^3$

Cylinder Area: $2\pi r h$

Cylinder Volume: $\pi r^2 h$



GOLDMAN EQUATION

$$J = -P \frac{zF\psi}{RT} \left[\frac{c^o - c^i e^{\left(\frac{zF\psi}{RT}\right)}}{1 - e^{\left(\frac{zF\psi}{RT}\right)}} \right]$$

zero flux $\psi = \frac{RT}{zF} \ln \left[\frac{c^o}{c^i} \right]$

zero potential $J = -P(c^o - c^i)$

net charge $Q = C \Delta E$
(coulombs) (volt)

capacitance per unit area ($\sim 1 \mu\text{F}/\text{cm}^2$)

for a spherical cell:

$$C = 4\pi r^2 C'$$

$$Q = \frac{4}{3}\pi r^3 C F$$

concentration

Goldman-Hodgkin-Katz equation (assuming only Na^+ , K^+ , and Cl^- are present):

$$\psi = \frac{RT}{F} \ln \left[\frac{P_{\text{Na}} C_{\text{Na}}^o + P_{\text{K}} C_{\text{K}}^o + P_{\text{Cl}} C_{\text{Cl}}^i}{P_{\text{Na}} C_{\text{Na}}^i + P_{\text{K}} C_{\text{K}}^i + P_{\text{Cl}} C_{\text{Cl}}^o} \right]$$

Goldman-Hodgkins-Katz equation (assuming a single cation (M^+) and anion (A^-) are present):

$$\psi = \frac{RT}{F} \ln \left[\frac{[\text{M}^+{}_i] + \frac{P_{\text{A}^-}}{P_{\text{M}^+}} [\text{A}^-{}_o]}{[\text{M}^+{}_o] + \frac{P_{\text{A}^-}}{P_{\text{M}^+}} [\text{A}^-{}_i]} \right]$$

(current)

$$I = zFJ$$

(Flux)

OHM'S LAW

$$V = IR$$

ohm

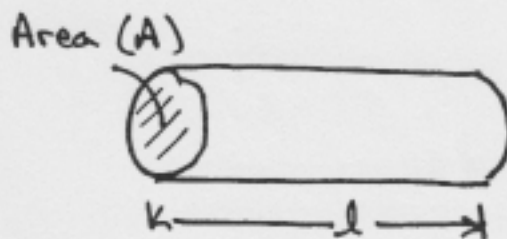
$$I = gV$$

siemens
coulombs/sec
Volt

Resistance

$$R = \rho \frac{l}{A}$$

resistivity
(ohm·cm)



(ca. 120 ohm·cm for 100 mM M^+A^-)

$$Re \text{ (Reynold's number)} \approx \frac{v L \rho}{\eta}$$

velocity
length
specific gravity
($\approx 1 \text{ gm cm}^{-3}$)
viscosity
($\approx 10^{-2} \text{ g/cm}\cdot\text{sec}$)

ATP bioenergetics:

7-10 kcal/mole

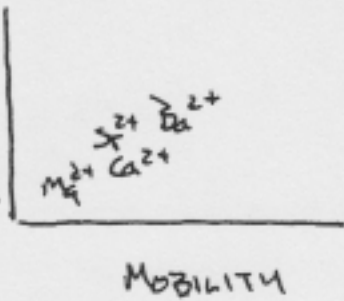
$$-n \cdot \Delta \mu^{H^+} = \Delta G^{ATP} = \Delta G^{\circ} + RT \ln \left[\frac{[ATP]}{[ADP] \cdot [P_i]} \right]$$

$$\Delta \mu^{H^+} = RT \ln \frac{[H^+]_i}{[H^+]_o} + F \Delta \psi$$

KE4

Q.1

Relative Permeability



Na⁺

diagrammatic.

higher charge density \Rightarrow hydrated radius
prediction on basis of mobility

/4
/4
/4

$\delta^- \delta^+$

-N-H to confer A⁻ selectivity.

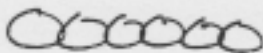
Permeability on basis of mobility

/4
/4

Q.2



sphere



cylinder

capacitance \propto to surface area.

impact on required Na⁺/K⁺ movement

narrow cylinder \rightarrow lower capacitance
(for an axon)

/10
/5
/5

Q.3

$$D = \frac{kT}{6\pi\eta a}$$

$$a = \frac{kT}{D6\pi\eta}$$

$$\frac{kT}{6\pi\eta} = 2.123 \times 10^{-13}$$

/10

$$a = \frac{2.123 \times 10^{-13}}{D}$$

for Na⁺, $= 1.6 \times 10^{-10} \text{ m}$
(1.6 Å)

compared to 0.95 Å

$$0.95 + 0.95 = 1.9 \text{ Å}$$

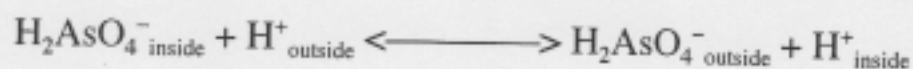
\therefore ca. 1 H₂O

/10

THIRD TERM TEST: Choose Two of the Three Questions

Question One

A. One possible mechanism for arsenate extrusion from *E. coli* cells lacking the Ars A gene of the ars operon is countertransport of H_2AsO_4^- and H^+ through the Ars B protein:



If the $[\text{H}_2\text{AsO}_4^-]_{\text{outside}}$ is 10 mM, internal pH is 7 and external pH is 4, and the membrane potential is -100 mV ($-ve$ inside), determine the effectiveness of arsenate extrusion by calculating $[\text{H}_2\text{AsO}_4^-]_{\text{inside}}$ under steady state conditions. Is $\text{H}_2\text{AsO}_4^- / \text{H}^+$ countertransport more effective than a H_2AsO_4^- channel?

B. Give an estimate of the pore size of a H_2AsO_4^- channel, with appropriate explanation(s). Discuss any implication(s).

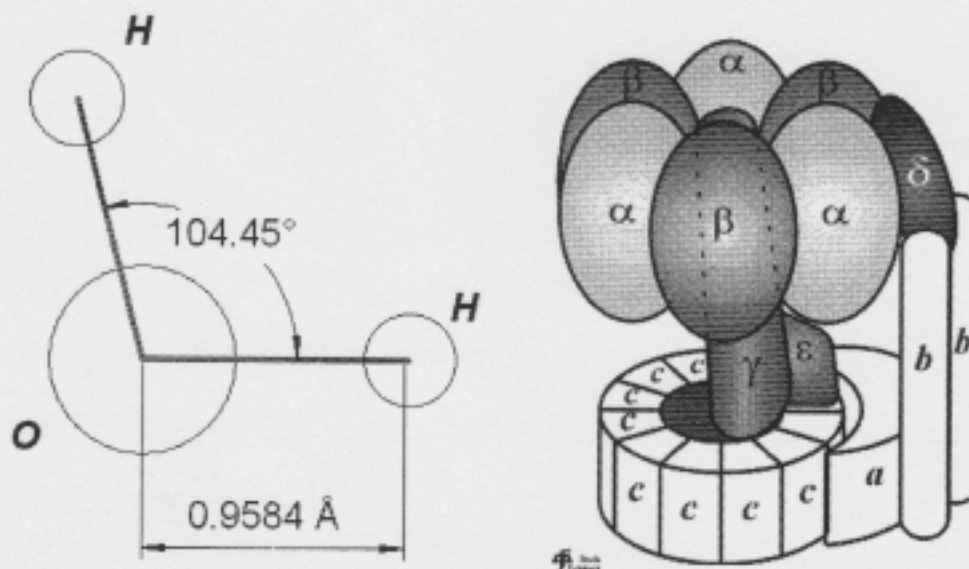
Ion Species	Ion Atomic Radius (Å)	ΔH° hydration (kcal/mole)	Mobility 10^{-4} (cm/sec)/(V/cm)
Tl^+	1.44	.	7.74
H^+	.	.	36.3
NH_4^+	1.48	.	7.52
Cs^+	1.69	-72	8.01
Rb^+	1.48	-79.2	8.06
K^+	1.33	-85.8	7.62
Na^+	0.95	-104.6	5.19
Li^+	0.6	-131.2	4.01
Cl^-	1.81	-82	7.92
F^-	1.36	-114	5.74
Br^-	1.95	-79	8.09
I^-	2.16	-65	7.96
NO_3^-	2.9	.	7.41
Mg^{2+}	0.65	-476	2.75
Ca^{2+}	0.99	-397	3.08
Sr^{2+}	1.13	-362	3.08
Ba^{2+}	1.35	-328	3.3

Question Two

If an ATP synthase were able to synthesize ATP from ADP and P_i using either a H^+ or Na^+ ionic gradient, which *one* of the other monovalent (+1 charge) ions is *most likely* to be capable of synthesizing ATP? Explain.

Question Three

Assuming that the ΔG_{ATP}° for ATP hydrolysis is -8.0 kcal/mole, at what potential ($\Delta\Psi$) will the enzyme operate in reverse, synthesizing ATP (assume the ΔpH is 'zero'; normal cytoplasmic [ATP] is about 5 mM, while [ADP] and [P_i] are both about 0.5 mM).



EQUATIONS

Sphere Area: $4 \cdot \pi \cdot r^2$

Sphere Volume: $\frac{4}{3} \cdot \pi \cdot r^3$

Cylinder Area: $2 \cdot \pi \cdot r \cdot h$

Cylinder Volume: $\pi \cdot r^2 \cdot h$

Goldman Equation: $J = -P \frac{zF\Psi}{RT} \cdot \left[\frac{c_o - c_i \cdot e^{\left(\frac{zF\Psi}{RT}\right)}}{1 - e^{\left(\frac{zF\Psi}{RT}\right)}} \right]$

zero flux: $\Psi = \frac{RT}{zF} \cdot \ln \left[\frac{c_o}{c_i} \right]$

zero potential: $J = -P \cdot (c_o - c_i)$

net charge: $Q = C \cdot \Delta E$

Charge (coulombs) = Capacitance (coulombs / volt) • Potential (volt)

for a spherical cell: $C = 4 \cdot \pi \cdot r^2 \cdot C'$

(C' is capacitance per unit area:
~ 1 μ F/cm²)

$$Q = \frac{4}{3} \cdot \pi \cdot r^3 \cdot c \cdot F \quad (c \text{ is the concentration})$$

Goldman - Hodgkin - Katz equation (assuming only Na⁺, K⁺ and Cl⁻ are present):

$$\Psi = \frac{RT}{F} \cdot \ln \left[\frac{P_{Na} C_{Na}^o + P_K C_K^o + P_{Cl} C_{Cl}^i}{P_{Na} C_{Na}^i + P_K C_K^i + P_{Cl} C_{Cl}^o} \right]$$

Goldman - Hodgkin - Katz equation (assuming a single cation (M⁺) and anion (A⁻) are present):

$$\Psi = \frac{RT}{F} \cdot \ln \left[\frac{\left[M_i^+ \right] + \frac{P_{A^-}}{P_{M^+}} \left[A_o^- \right]}{\left[M_o^+ \right] + \frac{P_{A^-}}{P_{M^+}} \left[A_i^- \right]} \right]$$

$$I = z F J$$

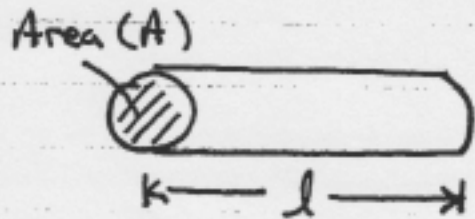
current flux

OHM'S LAW: $V = IR$ or $I = gV$

ohm Siemens Volt
coulombs/sec

RESISTANCE

$$R = \rho \frac{l}{A}$$



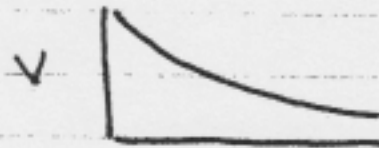
resistivity (ohm·cm)

(~ 120 ohm·cm for 100 mM M^+A^-)

CABLE

$$V = V_0 e^{(-x/\lambda)}$$

length constant for $x \geq 0$



Re (Reynold's number):

$$\frac{v \cdot l \cdot \rho}{\eta}$$

velocity length specific gravity
~ 1 gm cm⁻³
viscosity
~ 10⁻² g/cm·sec

ATP BIOENERGETICS

$$-n \cdot \Delta \mu^{H^+} = \Delta G^{ATP} = \Delta G^{\circ} + RT \ln \left[\frac{[ATP]}{[ADP][P_i]} \right]$$

$$\Delta \mu^{H^+} = RT \ln \left[\frac{[H^+]_i}{[H^+]_o} \right] + F \Delta \psi$$

Numerical Values of Constants and Coefficients

Symbol	Description	Magnitude
c	speed of light in vacuum	$2.998 \times 10^8 \text{ m s}^{-1}$
c_w^s	saturation concentration of water vapor (i.e., at 100% relative humidity)	See pp. 548-550 for values from -30°C to 60°C .
C_p^{water}	volumetric heat capacity of water at constant pressure (1 atmosphere, 0.1013 MPa)	4.217 MJ $\text{m}^{-3} \text{ }^\circ\text{C}^{-1}$ at 0°C 4.175 MJ $\text{m}^{-3} \text{ }^\circ\text{C}^{-1}$ at 20°C 4.146 MJ $\text{m}^{-3} \text{ }^\circ\text{C}^{-1}$ at 40°C
C_p^{dry}	volumetric heat capacity of dry air at constant pressure (1 atmosphere)	1.300 kJ $\text{m}^{-3} \text{ }^\circ\text{C}^{-1}$ at 0°C 1.212 kJ $\text{m}^{-3} \text{ }^\circ\text{C}^{-1}$ at 20°C 1.136 kJ $\text{m}^{-3} \text{ }^\circ\text{C}^{-1}$ at 40°C
D_{CO_2}	diffusion coefficient of CO_2 in air (1 atmosphere, 0.1013 MPa)	$1.33 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 0°C $1.42 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 10°C $1.51 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 20°C $1.60 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 30°C $1.70 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 40°C $1.95 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 20°C
D_{O_2}	diffusion coefficient of O_2 in air (1 atmosphere, 0.1013 MPa)	$2.13 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 0°C $2.27 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 10°C $2.42 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 20°C $2.57 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 30°C $2.72 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ at 40°C
D_{w}	diffusion coefficient of water vapor in air (1 atmosphere, 0.1013 MPa)	2.71828 ($1/e = 0.368$) $1.602 \times 10^{-19} \text{ C}$
e	base for natural logarithmic electronic charge	9.649 $\times 10^6$ coulomb mol^{-1} 9.649 $\times 10^6$ J $\text{mol}^{-1} \text{ V}^{-1}$ 2.306×10^6 cal $\text{mol}^{-1} \text{ V}^{-1}$ 23.06 kcal $\text{mol}^{-1} \text{ V}^{-1}$
F	Faraday's constant	
g	gravitational acceleration	9.780 m s^{-2} (sea level, 0° latitude) 9.807 m s^{-2} (sea level, 45° latitude) 9.832 m s^{-2} (sea level, 90° latitude) 978.0 cm s^{-2} (sea level, 0° latitude) 980.7 cm s^{-2} (sea level, 45° latitude) 983.2 cm s^{-2} (sea level, 90° latitude)
h	Planck's constant	$6.626 \times 10^{-34} \text{ J s}$
h_c		$6.626 \times 10^{-27} \text{ erg s}$
H_{sub}	heat of sublimation of water	$0.4136 \times 10^{-14} \text{ eV s}$ $1.584 \times 10^{17} \text{ kcal s}$ $1.986 \times 10^{25} \text{ J m}$ 1.240 eV nm
H_{vap}	heat of vaporization of water	51.37 kJ mol^{-1} (2.847 MJ kg^{-1}) at -10°C 51.17 kJ mol^{-1} (2.835 MJ kg^{-1}) at -5°C 51.00 kJ mol^{-1} (2.826 MJ kg^{-1}) at 0°C 12.27 kcal mol^{-1} (680 cal g^{-1}) at -10°C 12.22 kcal mol^{-1} (677 cal g^{-1}) at -5°C 12.18 kcal mol^{-1} (675 cal g^{-1}) at 0°C 45.06 kJ mol^{-1} (2.501 MJ kg^{-1}) at 0°C 44.63 kJ mol^{-1} (2.477 MJ kg^{-1}) at 10°C 44.21 kJ mol^{-1} (2.454 MJ kg^{-1}) at 20°C 44.00 kJ mol^{-1} (2.442 MJ kg^{-1}) at 25°C 43.78 kJ mol^{-1} (2.430 MJ kg^{-1}) at 30°C 43.35 kJ mol^{-1} (2.406 MJ kg^{-1}) at 40°C 42.91 kJ mol^{-1} (2.382 MJ kg^{-1}) at 50°C 40.68 kJ mol^{-1} (2.258 MJ kg^{-1}) at 100°C
k	Boltzmann's constant	$1.381 \times 10^{-23} \text{ J molecule}^{-1} \text{ K}^{-1}$ $1.381 \times 10^{-16} \text{ erg molecule}^{-1} \text{ K}^{-1}$ $8.617 \times 10^{-5} \text{ eV molecule}^{-1} \text{ K}^{-1}$
kT		0.02354 eV molecule^{-1} at 0°C 0.02526 eV molecule^{-1} at 20°C 0.02569 eV molecule^{-1} at 25°C 0.02699 eV molecule^{-1} at 40°C
K^{w}	thermal conductivity coefficient of dry air (1 atmosphere) ²	0.0237 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at -10°C 0.0243 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at 0°C 0.0250 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at 10°C 0.0257 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at 20°C 0.0264 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at 30°C 0.0270 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at 40°C 0.0277 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ at 50°C

1. The correction for height above sea level is $-3.09 \times 10^{-6} \text{ m s}^{-2}$ per m of altitude.
2. The pressure sensitivity is very slight, K^{w} increasing only about 0.0001 W $\text{m}^{-1} \text{ }^\circ\text{C}^{-1}$ per atmosphere (0.1013 MPa) increase in pressure.

Symbol	Description	Magnitude	Symbol	Description	Magnitude
K_{moist}	thermal conductivity coefficient of moist air (100% relative humidity, 1 atmosphere)	0.0242 W m ⁻¹ °C ⁻¹ at 0°C 0.0255 W m ⁻¹ °C ⁻¹ at 20°C 0.0264 W m ⁻¹ °C ⁻¹ at 40°C	RT/F		25.3 mV at 20°C 25.7 mV at 25°C
$\ln 2$	thermal conductivity coefficient of water	0.565 W m ⁻¹ °C ⁻¹ at 0°C 0.599 W m ⁻¹ °C ⁻¹ at 20°C 0.627 W m ⁻¹ °C ⁻¹ at 40°C	2.303 RT/F		58.2 mV at 20°C 59.2 mV at 25°C 60.2 mV at 30°C
N	Avogadro's number	0.6931	RT/V_c		135.0 MPa at 20°C 137.3 MPa at 25°C
N_{A}	saturation mole fraction of water vapor (i.e., at 100% relative humidity) at 1 atmosphere (0.1013 MPa)	6.0220 × 10 ²³ entities mol ⁻¹ 0.1196 J mol ⁻¹ m 119 600 kJ mol ⁻¹ nm 28.60 kcal mol ⁻¹ μm 28 600 kcal mol ⁻¹ nm	2.303 RT/V_c		32.31 cal cm ⁻³ at 20°C 135.0 J cm ⁻³ at 20°C 1 350 bars at 20°C 1 330 atmospheres at 20°C
P^*	saturation vapor pressure of water	See pp. 548-550 for values from -30°C to 60°C.		solar constant	310.9 MPa at 20°C 316.2 MPa at 25°C 3 063 atmospheres at 20°C 3 109 bars at 20°C
R	protonic charge gas constant	See pp. 548-500 for values from -30°C to 60°C. 1.602 × 10 ⁻¹⁹ C 8.314 J mol ⁻¹ K ⁻¹ 1.987 cal mol ⁻¹ K ⁻¹ 8.314 m ³ Pa mol ⁻¹ K ⁻¹ 8.314 × 10 ⁻⁴ m ³ MPa mol ⁻¹ K ⁻¹ 0.08205 litre atmosphere mol ⁻¹ K ⁻¹ 0.08314 litre bar mol ⁻¹ K ⁻¹ 83.14 cm ³ bar mol ⁻¹ K ⁻¹		thermal capacity of water (mass basis)	1 368 W m ⁻² 1.960 cal cm ⁻² min ⁻¹ 1.368 × 10 ⁹ erg cm ⁻² s ⁻¹ 0.1368 W cm ⁻²
RT		2.271 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 0°C 2.437 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 20°C 2.479 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 25°C 2.271 × 10 ³ m ³ MPa mol ⁻¹ at 0°C 2.437 × 10 ³ m ³ MPa mol ⁻¹ at 20°C 2.479 × 10 ³ m ³ MPa mol ⁻¹ at 25°C 542.4 cal mol ⁻¹ at 0°C 582.2 cal mol ⁻¹ at 20°C		thermal capacity of water (mole basis)	4 218 J kg ⁻¹ °C ⁻¹ at 0°C 4 182 J kg ⁻¹ °C ⁻¹ at 20°C 4 179 J kg ⁻¹ °C ⁻¹ at 40°C 1.0074 cal g ⁻¹ °C ⁻¹ at 0°C 0.9988 cal g ⁻¹ °C ⁻¹ at 20°C 0.9980 cal g ⁻¹ °C ⁻¹ at 40°C
		2.271 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 0°C 2.437 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 20°C 2.479 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 25°C 2.271 × 10 ³ m ³ MPa mol ⁻¹ at 0°C 2.437 × 10 ³ m ³ MPa mol ⁻¹ at 20°C 2.479 × 10 ³ m ³ MPa mol ⁻¹ at 25°C 542.4 cal mol ⁻¹ at 0°C 582.2 cal mol ⁻¹ at 20°C		partial molal volume of water	75.99 J mol ⁻¹ °C ⁻¹ at 0°C 75.34 J mol ⁻¹ °C ⁻¹ at 20°C 75.28 J mol ⁻¹ °C ⁻¹ at 40°C 18.14 cal mol ⁻¹ °C ⁻¹ at 0°C 17.99 cal mol ⁻¹ °C ⁻¹ at 20°C 17.98 cal mol ⁻¹ °C ⁻¹ at 40°C
		2.271 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 0°C 2.437 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 20°C 2.479 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 25°C 2.271 × 10 ³ m ³ MPa mol ⁻¹ at 0°C 2.437 × 10 ³ m ³ MPa mol ⁻¹ at 20°C 2.479 × 10 ³ m ³ MPa mol ⁻¹ at 25°C 542.4 cal mol ⁻¹ at 0°C 582.2 cal mol ⁻¹ at 20°C		permittivity of a vacuum	1.805 × 10 ⁻⁵ m ³ mol ⁻¹ at 20°C 18.05 cm ³ mol ⁻¹ at 20°C
		2.271 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 0°C 2.437 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 20°C 2.479 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 25°C 2.271 × 10 ³ m ³ MPa mol ⁻¹ at 0°C 2.437 × 10 ³ m ³ MPa mol ⁻¹ at 20°C 2.479 × 10 ³ m ³ MPa mol ⁻¹ at 25°C 542.4 cal mol ⁻¹ at 0°C 582.2 cal mol ⁻¹ at 20°C		viscosity of air	8.854 × 10 ⁻¹² coulomb ² m ⁻² N ⁻¹ 8.854 × 10 ⁻¹² coulomb m ⁻¹ V ⁻¹
		2.271 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 0°C 2.437 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 20°C 2.479 × 10 ³ J mol ⁻¹ (m ³ Pa mol ⁻¹) at 25°C 2.271 × 10 ³ m ³ MPa mol ⁻¹ at 0°C 2.437 × 10 ³ m ³ MPa mol ⁻¹ at 20°C 2.479 × 10 ³ m ³ MPa mol ⁻¹ at 25°C 542.4 cal mol ⁻¹ at 0°C 582.2 cal mol ⁻¹ at 20°C		viscosity of water	1.716 × 10 ⁻³ Pa s at 0°C 1.813 × 10 ⁻³ Pa s at 20°C 1.907 × 10 ⁻³ Pa s at 40°C 1.787 × 10 ⁻³ Pa s at 0°C 1.307 × 10 ⁻³ Pa s at 10°C 1.002 × 10 ⁻³ Pa s at 20°C 0.798 × 10 ⁻³ Pa s at 30°C 0.653 × 10 ⁻³ Pa s at 40°C 0.547 × 10 ⁻³ Pa s at 50°C 0.01002 dyn s cm ⁻² at 20°C 0.01002 poise at 20°C
2.303 RT		5.612 kJ mol ⁻¹ at 20°C 5.708 kJ mol ⁻¹ at 25°C 1.342 kcal mol ⁻¹ at 20°C 1.364 kcal mol ⁻¹ at 25°C 56 120 cm ³ bar mol ⁻¹ at 20°C			

Symbol	Description	Magnitude
ν_{air}	kinematic viscosity of air (dry, 1 atmosphere)	$1.327 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ at 0°C $1.505 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ at 20°C $1.691 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ at 40°C
ν_w	kinematic viscosity of water	$1.787 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ at 0°C $1.004 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ at 20°C $0.658 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$ at 40°C
π	circumference/diameter of circle	3.14159
ρ_{air}	density of dry air (1 atmosphere, 0.1013 MPa)	1.293 kg m^{-3} at 0°C 1.205 kg m^{-3} at 20°C 1.128 kg m^{-3} at 40°C
	density of saturated air (1 atmosphere) ³	1.290 kg m^{-3} at 0°C 1.194 kg m^{-3} at 20°C 1.097 kg m^{-3} at 40°C
ρ_w	density of water	999.8 kg m^{-3} (0.9998 g cm ⁻³) at 0°C 1000.0 kg m^{-3} (1.0000 g cm ⁻³) at 4°C 999.7 kg m^{-3} (0.9997 g cm ⁻³) at 10°C 998.2 kg m^{-3} (0.9982 g cm ⁻³) at 20°C 995.6 kg m^{-3} (0.9956 g cm ⁻³) at 30°C 992.2 kg m^{-3} (0.9922 g cm ⁻³) at 40°C
ρ_{-g}		$0.00979 \text{ MPa m}^{-1}$ (20°C, sea level, 45° latitude) $0.0979 \text{ bar m}^{-1}$ (20°C, sea level, 45° latitude) 979 dyn cm^{-2} (20°C, sea level, 45° latitude) $0.0966 \text{ atmosphere m}^{-1}$ (20°C, sea level, 45° latitude)
σ	Stefan-Boltzmann constant	$5.670 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$ $5.670 \times 10^{-12} \text{ W cm}^{-2} \text{ K}^{-4}$ $8.130 \times 10^{-11} \text{ cal cm}^{-2} \text{ min}^{-1} \text{ K}^{-4}$ $5.670 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ K}^{-4}$
σ_w	surface tension of water	0.0756 N m^{-1} (Pa m) at 0°C 0.0742 N m^{-1} (Pa m) at 10°C 0.0728 N m^{-1} (Pa m) at 20°C 0.0712 N m^{-1} (Pa m) at 30°C 0.0696 N m^{-1} (Pa m) at 40°C $7.28 \times 10^{-4} \text{ MPa m}$ at 20°C 72.8 dyn cm^{-1} at 20°C $7.18 \times 10^{-3} \text{ atmosphere cm}$ at 20°C $7.28 \times 10^{-3} \text{ bar cm}$ at 20°C

3. Moist air is less dense than dry air at the same temperature and pressure, because the molecular weight of water (18.0) is less than the average for air (29.0).

TABLE 1. LIMITING EQUIVALENT CONDUCTIVITIES, ELECTRIC MOBILITIES, AND DIFFUSION COEFFICIENTS OF IONS AT 25°C

Ion	$\lambda^0 = zFu$ [(S/cm)/(equiv/cm ²)]	$[10^{-4} \text{ (cm}^2\text{/V/cm)}]$	$D = RTu/F$ ($10^{-5} \text{ cm}^2\text{/s}$)
H ⁺	349.8	36.25	9.31
Li ⁺	38.7	4.01	1.03
Na ⁺	50.1	5.19	1.33
K ⁺	73.5	7.62	1.96
Rb ⁺	77.8	8.06	2.07
Cs ⁺	77.3	8.01	2.06
Tl ⁺	74.7	7.74	1.98
NH ₄ ⁺	73.6	7.52	1.96
CH ₃ NH ₃ ⁺	58.7	6.08	1.56
TMA ⁺	44.9	4.65	1.19
TEA ⁺	32.7	3.39	0.87
Mg ²⁺	53.0	2.75	0.71
Ca ²⁺	59.5	3.08	0.79
Sr ²⁺	59.4	3.08	0.79
Ba ²⁺	63.6	3.30	0.85
F ⁻	55.4	5.74	1.47
Cl ⁻	76.4	7.92	2.03
Br ⁻	78.1	8.09	2.08
I ⁻	76.8	7.96	2.04
NO ₃ ⁻	71.5	7.41	1.90
Acetate	40.9	4.24	1.09
SO ₄ ²⁻	80.0	4.15	1.06

Conductivities from Robinson and Stokes (1965).

TABLE 4. PAULING RADII AND IONIC HYDRATION ENERGIES

Atom or group	Radius (Å)	$\Delta H_{\text{hydration}}^{\circ}$ (kcal/mol)
H ⁺	—	-269
Li ⁺	0.60	-131
Na ⁺	0.95	-105
K ⁺	1.33	-85
Rb ⁺	1.48	-79
Cs ⁺	1.69	-71
Tl ⁺	1.40	—
Mg ²⁺	0.65	-476
Ca ²⁺	0.99	-397
Sr ²⁺	1.13	-362
Ba ²⁺	1.35	-328
Mn ²⁺	0.80	-458
Co ²⁺	0.74	-502
Ni ²⁺	0.72	-517
Zn ²⁺	0.74	-505
F ⁻	1.36	-114
Cl ⁻	1.81	-82
Br ⁻	1.95	-79
I ⁻	2.16	-65
H	1.20	—
Methyl	2.0	—
N	1.5	—
O	1.40	—

Radii from Pauling (1960). Standard enthalpies of hydration at 25°C are taken from Edsall and McKenzie (1978), who also give entropies and free energies of hydration.

Constants and Formulas

The following constants and formulas are useful for order-of-magnitude calculations. They are worth committing to memory. They are given in cgs units.

kT	The energy of thermal fluctuation, where k is Boltzmann's constant and T is the absolute temperature: 4×10^{-14} g cm ² /sec ² (ergs) at room temperature.
D_w	The diffusion coefficient of water in water at room temperature: 10^{-5} cm ² /sec.
η_w	The coefficient of viscosity of water at room temperature: 10^{-2} g/cm sec (poise).
$6\pi\eta a v$	The viscous drag (in g cm/sec ² = dynes) on a sphere of radius a (cm) moving at velocity v (cm/sec) through a medium of viscosity η .
$D = kT/6\pi\eta a$	The translational diffusion coefficient of a sphere of radius a in a medium of viscosity η .
$D_r = kT/8\pi\eta a^3$	The rotational diffusion coefficient of a sphere of radius a in a medium of viscosity η .
$\langle x^2 \rangle = 2Dt$	The mean-square displacement (cm ²) in each dimension of a particle of translational diffusion coefficient D in time t (sec).
$\langle \theta^2 \rangle = 2D_r t$	The mean-square angular displacement (radians ²) about an axis of a particle of rotational diffusion coefficient D_r in time t .
$N(x) = N(0)e^{- E(x)-E(0) /kT}$	The equilibrium distribution of numbers of particles $N(x)$ in states of energy $E(x)$.

Question one

Countertransport.

At steady state equil: $\Delta\mu_{As^-} = -\Delta\mu_{H^+}$

$$\Delta\mu_{H^+} = RT \ln \frac{[H^+]_i}{[H^+]_o} + \overset{+ve}{z}F(-0.1V) \quad /8$$

$$\frac{1}{2} \Delta\mu_{As^-} = zT \ln \frac{[As^-]_o}{[As^-]_i} + \overset{-ve}{z}F(-0.1V)$$

$[As^-]_i$ ca. 10^4 -fold lower than $[As^-]_o$ /4

Channel

$$-0.1V = \frac{zT}{zF} \ln \frac{[As^-]_o}{[As^-]_i}$$

$[As^-]_i$ ca 55-fold lower than $[As^-]_o$ /4

Pore size.

larger than NO_3^- (2.9 Å + hydration)

If non-selective, may cause A^- leakage

/4

Question Two

Li^+ . The reasons are:

- atomic radius closest to Na^+
compared to other M^+
- mobility also closest

/10

/5

/5

Question Three

At reversal, $\Delta G = 0$

/8

$$-\Delta\mu_{H^+} = \Delta G_{ATP}$$

$$-zF\psi$$

23.06

$$\Delta G_{ATP}^{\circ} + RT \ln \frac{[ADP][P_i]}{[ATP]}$$

/8

$$\underbrace{-8}_{-8} \quad \underbrace{1.342}_{-4.020}$$

-12

$$\psi = 521 \text{ mV}$$

/4

$$\Delta G_{ATP} = \Delta G_{ATP}^{\circ} + 2.303 \cdot R \cdot T \log \frac{[ADP][P_i]}{[ATP]}$$

$\underbrace{1.342}_{\text{kcal/mole (25}^{\circ}\text{C)}} \quad \underbrace{\frac{(0.5)(0.5)}{(5)}}_{-1.301}$
 $\underbrace{\hspace{10em}}_{-1.746}$

$$-100 = 55 \log \frac{A_{50}}{A_{5i}}$$

$$\frac{1.918}{10} = 65.765$$

$$A_{5i} = 0.153 \text{ mM}$$

$$\Delta G_{ATP} = -11.746 \text{ kcal/mole}$$

$$-11.746 = \Delta \mu_{As} = \underbrace{2.303 \cdot R \cdot T \log \frac{[As_o]}{[As_i]}}_{1.342} + z F \Delta \varphi$$

$\begin{matrix} -1 \\ \uparrow \\ z F \Delta \varphi \\ \downarrow \\ -100 \text{ mV} \end{matrix}$

$$23.06 \text{ kcal/mole V}$$

$$+ 2.306 \text{ kcal/mole}$$

$$\frac{-14.052}{-1.342}$$

$$+10.481 = \log \frac{A_{50}}{A_{5i}}$$

kcal/mole

$$3.38 \times 10^{11} = \frac{10 \text{ mM}}{A_{5i}}$$

$$A_{5i} = 29.59 \text{ pM}$$

$$A_{5i} = 29.59 \text{ pM}$$