NAME

GROUND RULES: This is a closed-book/closed-note exam, except that you are permitted two sheets of notes. Do your work on the paper provided. Please be sure that your name is written on each page you submit. Also, please be sure that the problem number and your answer are clearly indicated. The total score possible is 20 points, and the time allowed is 50 minutes. Use the time wisely. Good luck!

REMINDER: Read the questions **carefully**, and be certain you are responding appropriately.
HINTS:
(1) If you seem to be missing an important piece of information, assume a reasonable value, state your assumption, and proceed.
(2) Partial credit is granted, but only if your work can be understood (and your thinking is reasonable).
(3) See below for potentially relevant information.

#1 (4 possible)	________	#2 (6 possible)	________
#3 (10 possible)	________	TOTAL (of 20)	

Results: UG N = 37, average = 12.2; G N = 6, average = 16.3

DATA AND RELATIONSHIPS

ATOMIC MASSES (g/mol): H - 1, C - 12, N - 14, O - 16

IDEAL GAS LAW: $pV = nRT$

GAS CONSTANT: $R = 82.05 \times 10^{-6}$ atm mol^{-1} m^3 K^{-1}

CONVERSION FACTORS:
- pressure: 1 atm = 1.01325×10^5 Pa
- volume: 10^{-3} m^3 = 1 L = 1000 cm^3
- mass: 10^{-3} kg = 1 g = 10^3 mg = 10^6 µg

TWO-FILM MODEL: $J_{gl} = k_{gl} (C_s - C)$

MATERIAL BALANCES FOR REACTOR MODELS:
- batch: $dC/dt = [dC/dt]_{rxn} + [dC/dt]_{imt}$
- CMFR: $d(CV)/dt = Q_{in} C_{in} - Q_{out} C + [d(CV)/dt]_{rxn} + [d(CV)/dt]_{imt}$
- PFR: $dC/d\Theta_x = [dC/dt]_{rxn} + [dC/dt]_{imt}$

RATE LAW, 1st-order decay: $[dC/dt]_{rxn} = - k C$

INTERFACIAL MASS TRANSFER: $[dC/dt]_{imt} = J_{gl} A/V$

DYNAMIC EQUATION and SOLUTION:
- problem statement: $dC/dt = S - L C$; $C(0) = C_o$; S,L constant
- solution: $C(t) = C_o \exp(-Lt) + (S/L) [1-\exp(-Lt)]$

1. ENVIRONMENTAL TRANSPORT BASICS (4 points)

(a) Fick's law in one dimension is J = - D dC/dx. Define the variable D and give the associated dimensions.

(b) In deriving the two-film model, two variables that appear are P_i, the partial pressure of the species in air at the interface, and C_i, the aqueous concentration at the interface. What theory or principle is used to relate C_i to P_i in deriving the two-film model?

(c) Name the two properties of a fluid that contribute to the drag on a suspended particle.

(d) In your own words, define "dispersion" as a concept in environmental transport.

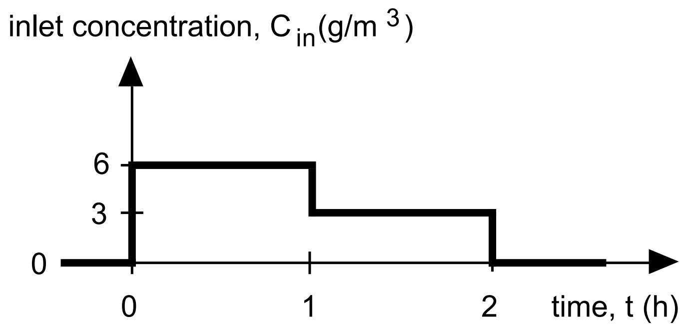
2. REACTOR MODELS (6 points; 3 each)

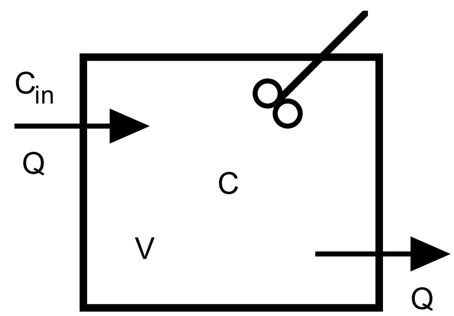
(a) Water contains two species, A and B, which react according to the following kinetic expression:

$$A + B \rightarrow \text{products} \qquad R = k\,[A]$$

Water flows through a PFR with a hydraulic detention time of θ. At the inlet to the PFR, the concentrations of A and B are A_o and B_o, respectively. What are the concentrations of A and B at the reactor outlet? [*Hint:* Assume that B_o is sufficient such that [B] > 0 at the outlet.]

(b) A CMFR contains water at a volume V = 2 m^3. Water flows through the reactor at a balanced rate Q = 0.5 $m^3\ h^{-1}$. Consider a nonreactive contaminant. Within the reactor, the contaminant concentration is C, and the initial condition is C(t=0) = 0. Given the following time-dependent inlet concentration, what is the maximum concentration, C_{max}, in the reactor?





3. CRYPTO (10 points)

As background to this problem, read the following three quotes.

"Cryptosporidiosis is a diarrheal disease caused by microscopic parasites of the genus *Cryptosporidium*. Once an animal or person is infected, the parasite lives in the intestine and passes in the stool. The parasite is protected by an outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine-based disinfectants. Both the disease and the parasite are commonly known as 'crypto.' During the past two decades, crypto has become recognized as one of the most common causes of waterborne disease within humans in the United States. The parasite may be found in drinking water and recreational water in every region of the United States and throughout the world." — 2004 Fact Sheet from the US Centers for Disease Control.

"Cryptosporidium parvum is a small protozoan parasite, 2-6 μm in size depending on the stage of the life cycle, that invades and replicates within the microvillous region of epithelial cells

lining the digestive and respiratory organs of mammals. … Water suppliers have been concerned that conventional treatment methods may not be a sufficient barrier to waterborne transmission of cryptosporidiosis." — LL Gyürék et al., *ASCE Journal of Environmental Engineering* 123, 865-875, 1997.

"In 1993 a waterborne cryptosporidiosis outbreak occurred in Milwaukee, Wisconsin. An estimated 403,000 people became ill, including 4,400 people hospitalized." — *WIkipedia*

Consider a conventional municipal drinking water treatment plant, as we have been studying. [*Hint*: Each of these questions can be answered independently and in any order. Note that in parts (a) and (b) you can consider an efficiency of $\eta > 90\%$ as clearly "effective," and an efficiency of $\eta < 10\%$ as clearly not "effective."]

(a) Would a well-designed sedimentation basin be effective in helping to control crypto? Explain. (2 points)

(b) Would a well-designed sand filter be effective in helping to control crypto? Explain. (2 points)

(c) The disinfection kinetics for *Cryptosporidium* inactivation with free chlorine have been measured in the laboratory (Korich et al., 1990). Researchers report that a CT value of 7200 (mg/L) min generated 2-log inactivation. Consider a disinfection contact basin configured as an ideal PFR. The free chlorine concentration is 10 mg/L. What contact time is necessary to achieve 90% inactivation of *Cryptosporidium*? (4 points) (*Hint*: Assume that Chick's Law and Watson's Law apply. Assume in Watson's Law that $n = 1$.)

(d) It has been suggested that the crypto problem could be practically controlled if conventional drinking water treatment processes were augmented with membrane filtration. In one concept, water would be passed through a membrane filter after the sedimentation + filtration + chemical disinfection processes. The table below gives properties of five membrane types. Which of these would be *best* suited for controlling crypto? Explain. (2 points)

Membrane type	**Characteristics**
Reverse osmosis (RO)	Suitable for converting seawater and brackish water to drinking water. Requires high pressure differences because of small pore size.
Electrodialysis	Removes ions from water by applying transverse electric field. Requires much lower pressure drop than RO membrane. Suitable for desalination of brackish waters, but not seawater.
Microfiltration	Pore dimensions are about a micrometer and are designed to remove particles.
Ultrafiltration	Smaller pores than microfiltration. Suitable for capturing large organic molecules, but not ions.
Nanofiltration	Uses RO-type membranes with low pressure to accomplish water softening.

References

DG Korich et al., *Applied and Environmental Microbiology* 56, 1423-1428, 1990.