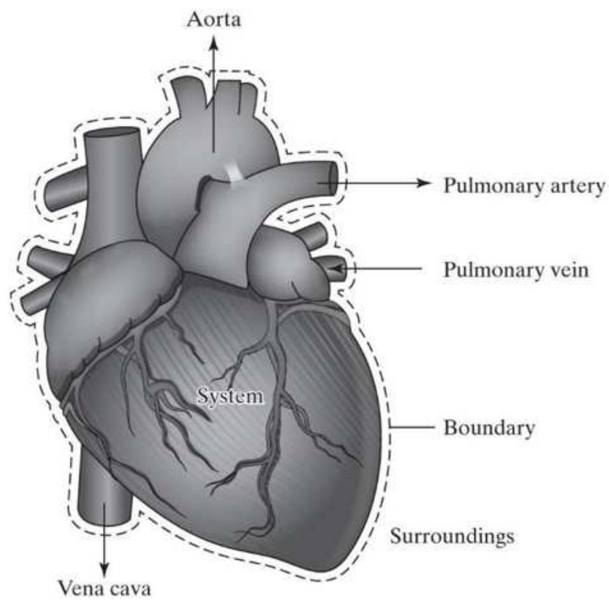
CHAPTER 2 SOLUTIONS

2.1

i. System diagram.



ii. Blood is an extensive property of the heart system.

iii. See above diagram.

iv. To look at different points in the cardiac cycle, the time period of interest is one second or less.

v. The system is open since blood is flowing in and out of the heart.

vi. The system is dynamic since the system parameters (e.g. temperature, pressure, flow rate) change over the cardiac cycle.

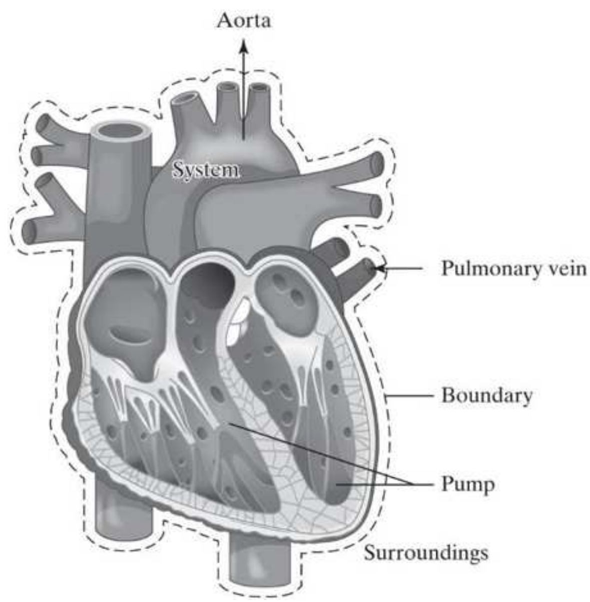
vii. The system is non-reacting since no blood is generated or consumed in the heart; the blood simply passes through. (Note: The composition of the blood does change in the coronary arteries and veins.)

viii. A differential equation best describes the system as it incorporates rates and the instantaneous time interval.

ix. Blood is conserved in the system – no blood is generated or consumed.

2.2

i. System diagram.



ii. Momentum is an extensive property of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous and ongoing time period.

v. The system is open since momentum is carried into the system via bulk transfer and the momentum (force) from the pump is also added.

vi. The system is in steady-state – momentum does not accumulate in the system.

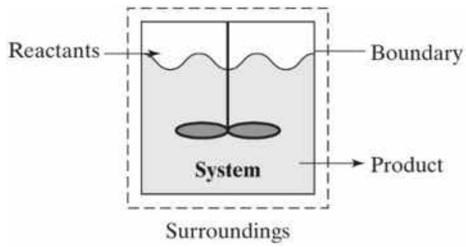
vii. The system is non-reacting since there is no reaction information given and no energy interconversions occur.

viii. The system can be described using an integral equation as it incorporates rates and a fixed time interval (e.g. 1 hr). A differential equation can also describe the system, as it incorporates rates and ongoing time intervals.

ix. Momentum is conserved by definition.

2.3

i. System diagram.



ii. The drug is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of time of the reaction.

v. The system is closed. The problem asks to only consider the time that the reaction is proceeding (i.e. after the reactants have been put in and before they have been removed as products).

vi. The system is dynamic since the system parameters (e.g. concentration) chance with respect to time. Also, the drug is accumulating in the bioreactor.

vii. The system is reacting since the drug is being produced by biological and/or chemical reactions.

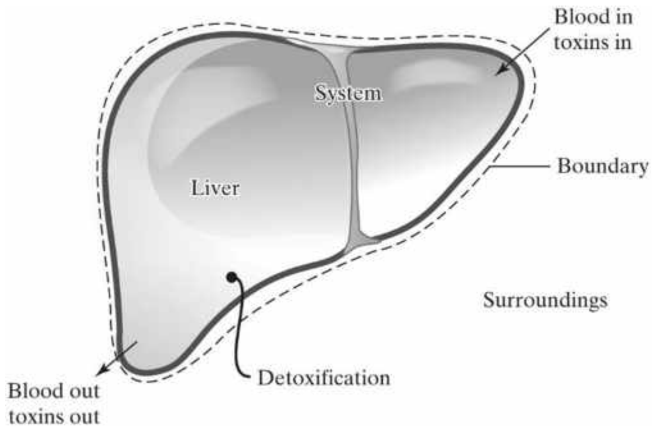
viii. An integral equation best describes the system as it incorporates rates and tracks the system over a fixed interval of time.

ix. The total and element masses are conserved in reacting systems. The species mass, species moles, and total moles are not conserved.

- Mass of drug: Not conserved
- Total mass: Conserved
- Chemical elements: Conserved
- Moles of drug: Not conserved
- Total moles: Not conserved

2.4

i. System diagram.



ii. Both the mass and moles of the toxins in the system are extensive properties of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous, ongoing time period.

v. The system is open since toxins move into and out of the liver in the blood.

vi. The system is in steady-state since the conditions of the liver do not change with time and no accumulation occurs.

vii. The system is reacting since the toxins undergo a chemical and/or biological transformation.

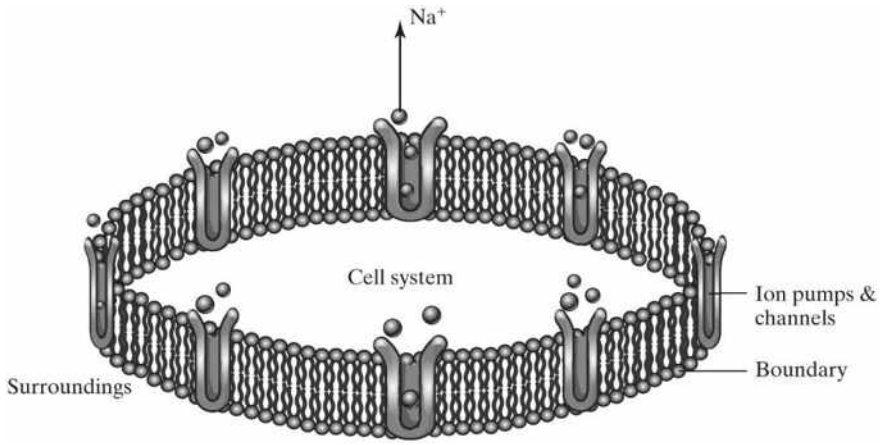
viii. A differential equation best describes the system as it incorporates rates and ongoing time intervals.

ix. The constituent mass and moles are not conserved in reacting systems.

- Mass of toxin: Not conserved
- Moles of toxin: Not conserved
- Total mass: Conserved

2.5

i. System diagram.



ii. Positive charge is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is instantaneous as we are modeling the moment that Na^+ ions traverse the cell membrane.

v. The system is open since Na^+ ions cross from the cell through the pumps into the surroundings.

vi. The system variables do not obviously change with time; however, there will be a difference between the initial and final masses and charges of Na^+ ions in the system. Therefore, the system is dynamic since the accumulation term is nonzero.

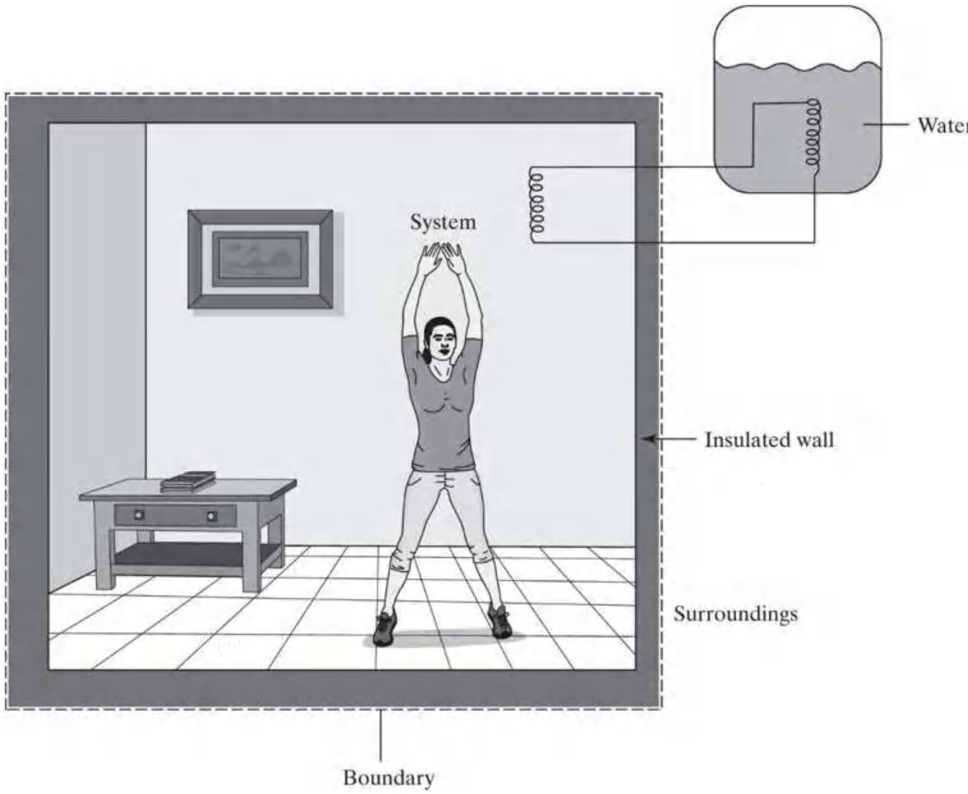
vii. The system is non-reacting since Na^+ ions are neither generated on consumed in the cell.

viii. A differential or integral equation best describes the system as rates of movement or Na^+ ions are involved.

ix. Positive charge is generally not conserved, but total charge is conserved. However, since there are no reactions in this system, positive charge is conserved.

2.6

i. System diagram.



ii. Total energy is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of time of exercise.

v. The system is open as energy leaves the system in air as a bulk material.

vi. The system is in steady-state since variables such as temperature and pressure do not change. Additionally, the total energy in the calorimeter remains constant.

vii. There are energy interconversions when the person's metabolic rate is considered.

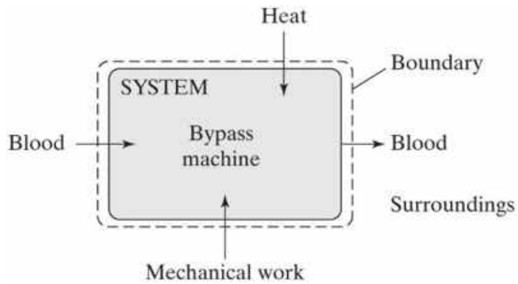
viii. An integral equation best describes the system as it incorporates rates and a defined time period.

ix. Total energy is always conserved.

Note: These questions can also be answered using thermal energy as the extensive property. In that case, thermal energy is not conserved.

2.7

i. System diagram.



ii. Energy is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of time of the operation.

v. The system is open since energy is being carried into and out of the system in the blood. Also, work and heat are added to the system.

vi. The system is in steady-state since the system is under constant operating conditions.

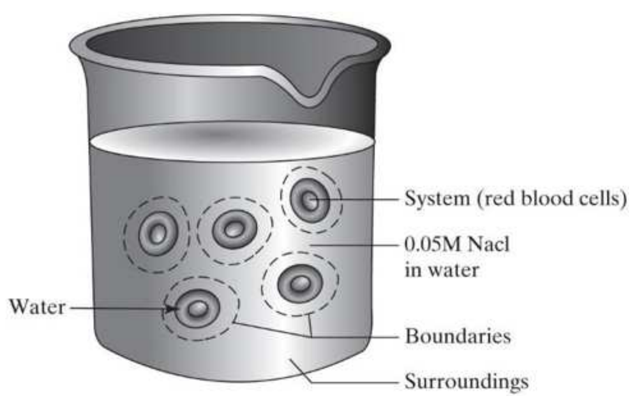
vii. The system is non-reacting since there is no reaction information given.

viii. A differential or integral equation describes the system as rates are incorporated. An integral equation is preferred since the problem defines a time period for the system.

ix. Total energy is conserved; however, mechanical and thermal energies are generally not conserved.

2.8

i. System diagram.



ii. The water in the red blood cells is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is not given in the problem, but is likely less than 30 minutes.

v. The system is open since the water is crossing membranes to enter red blood cells.

vi. The system is dynamic since the water in the red blood cells changes as it accumulates as a function of time. The initial and final contents of water in the red blood cells are not the same.

vii. The system is non-reacting since the problem states that no metabolic activity is used to generate water.

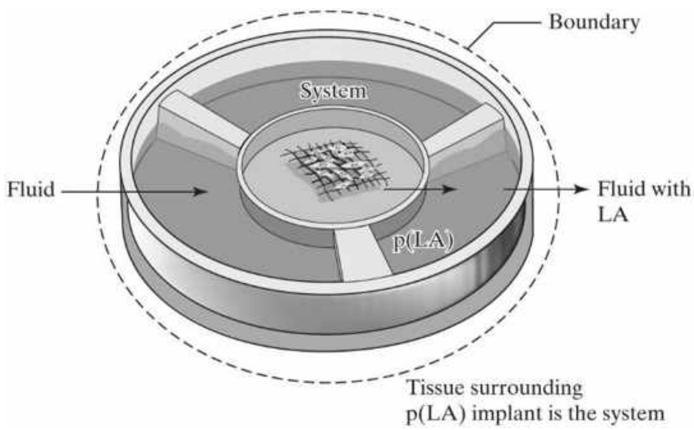
viii. An integral equation best describes the system as it incorporates rates and a finite time interval.

ix. The total mass of water is conserved because there is no generation or consumption of water.

Note: The size of the system will increase as a function of time.

2.9

i. System diagram.



ii. Both the masses of p(LA) and LA are extensive properties of the system.

iii. See above diagram.

iv. The time period of interest is the time it takes to degrade p(LA). The time period can also be considered continuous or instantaneous.

v. The LA system is open since LA is allowed to leave the system. Fluid moves in and out of the system with bulk transfer. The p(LA) system is closed – bulk matter moves in and out of the system, but p(LA) does not move across the system boundary.

vi. The system is in steady-state if considering a continuous time period and dynamic if considering the length of time that it takes for p(LA) to degrade.

vii. The system is reacting since p(LA) degrades to LA.

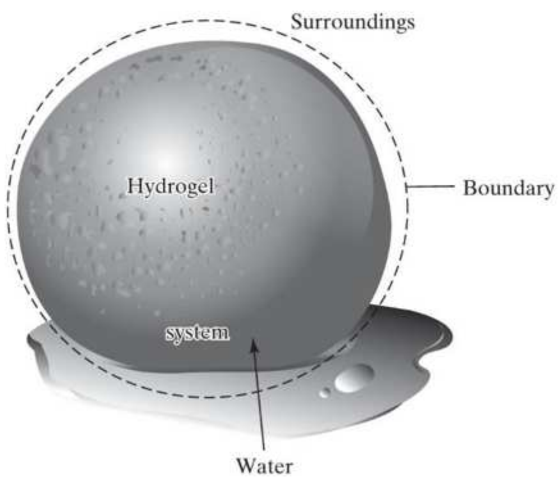
viii. An integral equation can be used to describe the system since the degradation rate of p(LA) and the generation rate of LA is not constant over time.

ix. LA and p(LA) are not conserved since LA is generated and p(LA) is consumed in the chemical reaction that takes place in the system.

- Mass of LA: Not conserved
- Moles of LA: Not conserved
- Mass of p(LA): Not conserved
- Fluid: Conserved
- Mass of Carbon: Conserved
- Mass of H^+: Conserved

2.10

i. System diagram.



ii. Water is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is 1 hour.

v. The system is open since water enters the system through bulk mass transfer.

vi. The system is dynamic since snapshots of the water content in the hydrogel change with time.

vii. The system is non-reacting – water absorption is not a chemical reaction.

viii. An integral equation best describes the system – rates are present since water absorption is occurring in a time-dependent manner. Also, it is important to look at two discrete time points.

ix. Water is conserved since there are no reactions in the system.

Hydrogel can also be considered an extensive property of the system. Below is the problem when hydrogel is considered.

i. System diagram.

ii. The hydrogel is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is 1 hour.

v. The system is open since water moves into the system; however, when considering the hydrogel, it does not move across the system boundary. A balance on the hydrogel would show that the system is closed.

vi. The system is dynamic since it changes volume as it absorbs water. When looking at the hydrogel, the system can also be considered steady-state since the hydrogel itself has the same initial and final conditions.

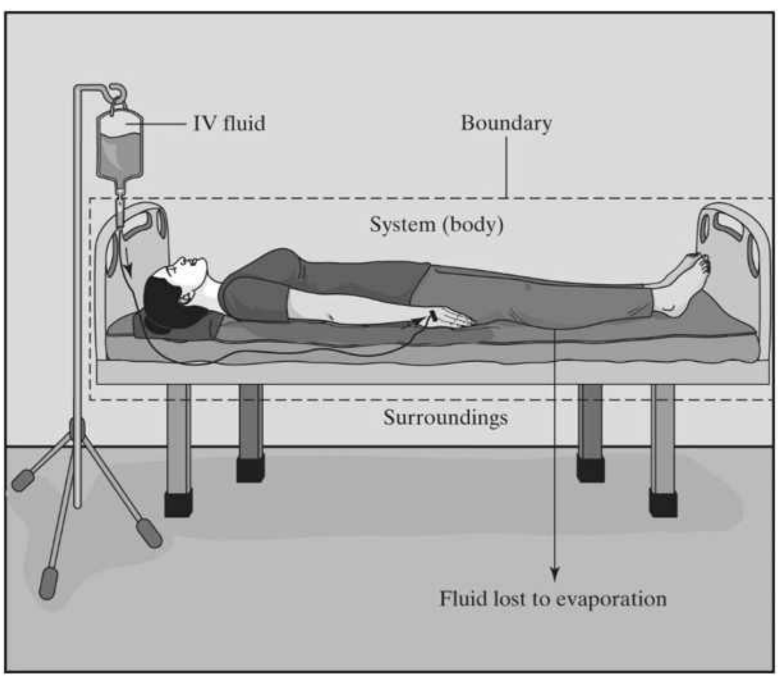
vii. The system is non-reacting – water absorption is not a chemical reaction.

viii. An integral equation describes the system for the same reasons as listed above. The system can also possibly be described by an algebraic equation since the hydrogel is not changing with time.

ix. The hydrogel is conserved since there are no chemical reactions.

2.11

i. System diagram.



ii. The fluid in the body is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the time period of patient stabilization.

v. The system is open since fluids enter and leave the body.

vi. The system is dynamic since the fluids in the body change over time as the IV is administered.

vii. The system is non-reacting since no reaction information is given in the problem.

viii. An integral equation best describes the system as it incorporates rates over a fixed time period.

ix. The fluid is conserved since there are no reactions in the system.

The system can also be analyzed at the time period after the patient is stabilized.

i. System diagram.

ii. The fluid in the body is an extensive property of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous, ongoing time period.

v. The system is open since fluids enter and leave the body.

vi. The system is in steady-state – once the patient has been stabilized, snapshots of the body should appear the same.

vii. The system is non-reacting since no reaction information is given in the problem.

viii. A differential equation best describes the system as it incorporates a continuous time period.

ix. The fluid is conserved since there are no reactions in the system.

2.12

i. System diagram.

ii. The mass of the blood in the body is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is 30 minutes.

v. The system is open since blood leaves the body.

vi. The system is dynamic since the amount of blood in the body decreases.

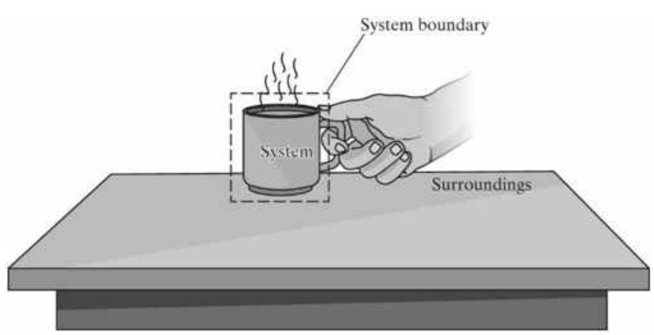
vii. The system is non-reacting – there are no chemical reactions and no energy interconversions.

viii. An integral or algebraic equation can be used to describe the system. An integral equation is more appropriate if rate information is given.

ix. Blood is conserved since it is neither generated nor consumed.

2.13

i. System diagram.



ii. The rate of energy is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the time the coffee remains in the cup (before it has been completely drunk).

v. The system is open if considering both the energy loss through the cup wall and the coffee being drunk. The system is closed if only the energy loss through the cup wall is considered.

vi. The system is dynamic since the energy of the system changes over time.

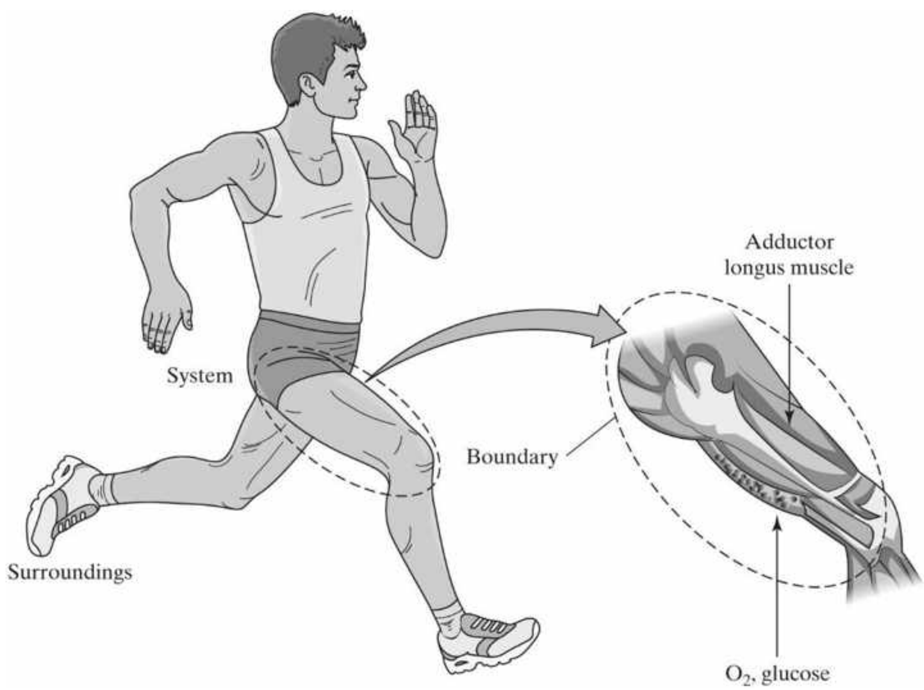
vii. The system is non-reacting and there are no energy interconversions.

viii. A differential or integral equation can be used to describe the system. An integral equation is more appropriate when considering the time until the coffee has been drunk.

ix. Coffee and total energy are conserved. Thermal energy is not conserved.

2.14

i. System diagram.



ii. The chemical compounds O_2, CO_2, glucose, and lactate are extensive properties of the system.

iii. See above diagram.

iv. The time period of interest is the time of 100-meter race, in which the chemical compounds are generated or consumed.

v. The system is open because O_2 and glucose travel through the bloodstream to reach the muscle.

vi. The system is dynamic because CO_2 and lactate are accumulating in the muscle (the problem does not mention any metabolic waste removal).

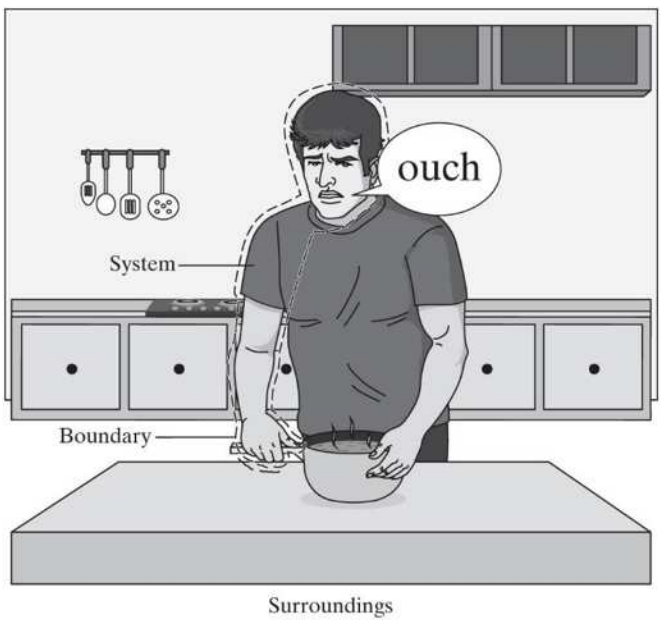
vii. The system is reacting because metabolic products are generated and reactants are consumed.

viii. An integral equation best describes the system because the reactants and products can be generated or consumed at a specific rate over two distinct times points (the beginning and the end of the race).

ix. The chemical compounds are not conserved because the products and reactants are generated and consumed.

2.15

i. System diagram.



ii. The current is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the finite time period between the roommate grabbing the pot and the roommate screaming.

v. The system is open since the current crosses the system boundary to get to the brain.

vi. The system is dynamic – the current throughout the system changes over time.

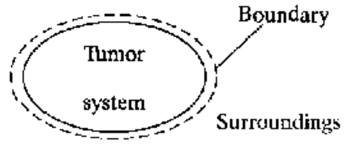
vii. The system is non-reacting – with the current as the property of interest, there are no chemical reactions or energy interconversions.

viii. An integral equation best describes the system as it incorporates rates and a finite time period.

ix. Charge is conserved since there are no reactions or energy interconversions.

2.16

i. System diagram.



ii. Tumor cells are an extensive property of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous, ongoing time period that encompasses the length of time the tumor is growing.

v. The system is open – typically, tumor cells require vascularization and nutrients for rapid proliferation, making this an open system.

vi. The system is dynamic because tumor cells are being generated through replication and accumulating in the system.

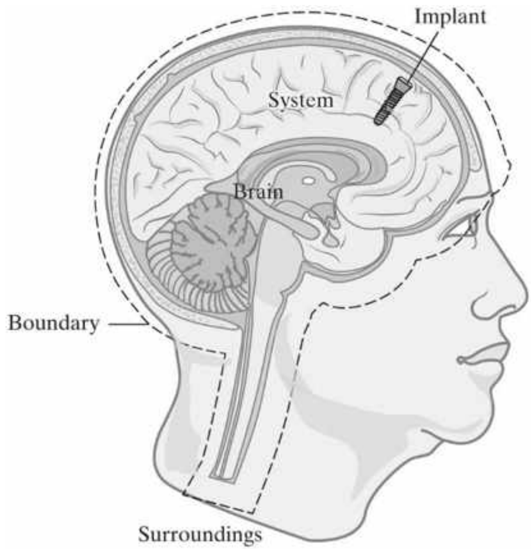
vii. The system is reacting because cells are replicating and dividing – a biological reaction.

viii. A differential equation best describes the system as it incorporates a tumor growth rate and a continuous reaction time period.

ix. Tumor cells are not conserved because they are generated. The system is the tumor, which expands and grows in size and shape as more tumor cells are generated. Thus, the system boundary changes as the system changes.

2.17

i. System diagram.



ii. The mass of NGF is an extensive property of the system.

iii. See above diagram. (The system includes the brain and the NGF implant.)

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous, ongoing time period that encompasses the length of time NGF is released. The time period of interest can also be considered a finite length time from NGF implantation to the final release of NGF.

v. The system is closed since no NGF travels across the system boundary.

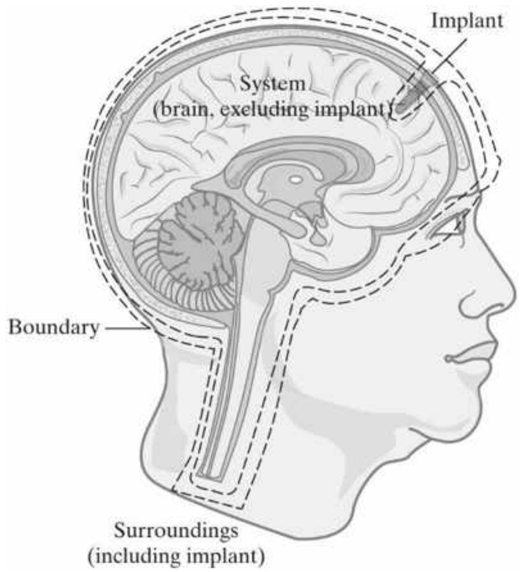
vi. The system is dynamic since snapshots of the system over time show a decrease in NGF.

vii. The system is reacting since NGF is consumed by cells in the brains.

viii. A differential or integral equation can be used to describe the system. An integral equation is more appropriate when using a finite time interval.

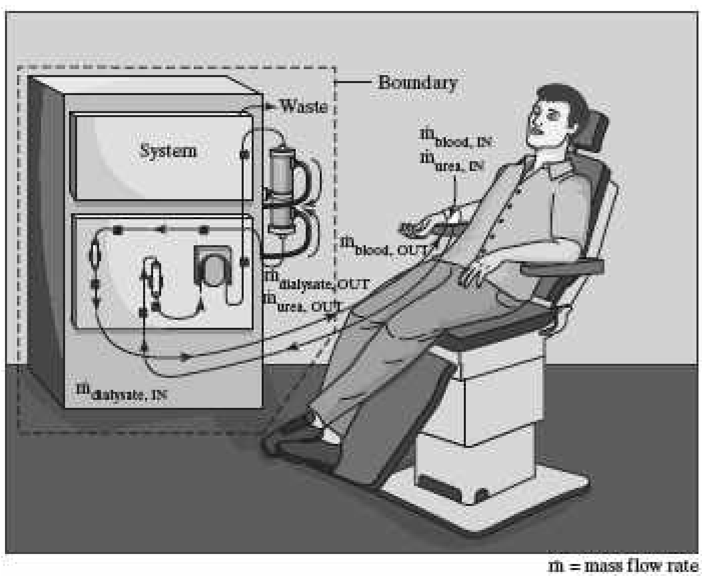
ix. NGF is not conserved since it is consumed in the reaction.

This can also be modeled in a system where NGF is excluded from the system boundary.



2.18

i. System diagram.



ii. Urea is an extensive property of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous, ongoing time period that encompasses the length of time that the dialysis machine is running.

v. The system is open since mass is entering and leaving the system through bulk transport.

vi. The system is dynamic since the dialysate machine is constantly accumulating urea as blood passes through it.

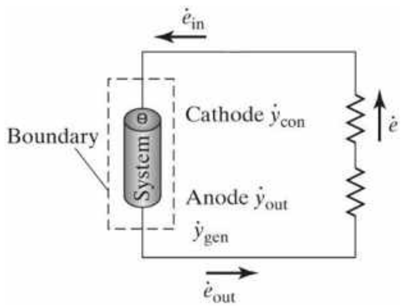
vii. The system is non-reacting since urea is only being filtered from the system and does not react with the system.

viii. A differential equation best describes the system as it incorporates rates and an ongoing time period.

ix. The mass of urea in the system is conserved since it is neither generated nor consumed.

2.19

i. System diagram.



ii. The rate of electrons passing through the battery is an extensive property of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume an ongoing time period that encompasses the length of time that the battery is discharging.

v. The system is closed – even though electrons are passing between the system and its surroundings, no mass is being transferred across the system boundary.

vi. The system is in steady-state. The electrons pass through the anode and then the circuit before returning to the cathode. Over time, snapshots of the system show that the number of electrons are constant as the electrons generated by the chemical reaction and then consumed at the cathode of the battery. This process continues until the reagents driving the chemical reaction are used up and electrons are no longer generated. This is often called a “dead” battery.

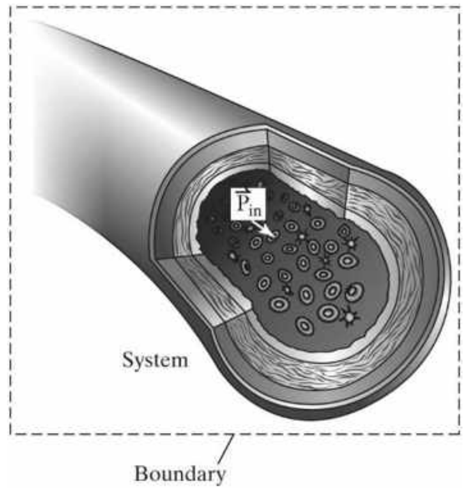
vii. The system is reacting since the electrons moving throughout the circuit are generated by a chemical reaction.

viii. A differential equation best describes the system as it incorporates rates.

ix. Electrons are not conserved in this system. They are being generated and consumed as the chemical reaction proceeds.

2.20

i. System diagram.



ii. Linear momentum is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of the collision between the blood cell and platelet.

v. The system is open since mass is entering the system through bulk transfer.

vi. The system is in steady-state since all linear momentum that begins in the system is still present after the collision.

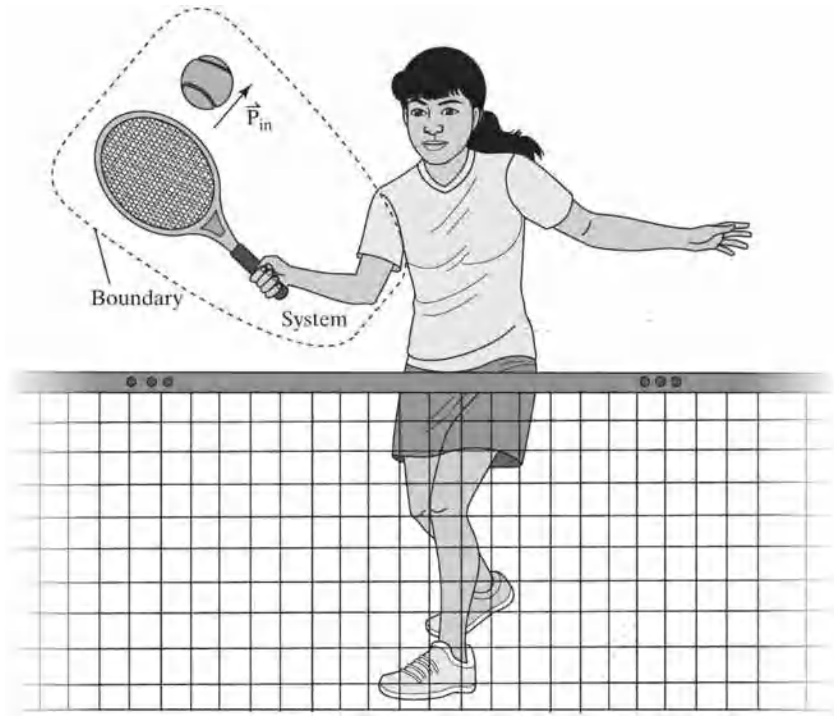
vii. The system is non-reacting – no chemical reactions or energy interconversions occur.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

ix. Linear momentum is a conserved property. It is neither generated nor consumed in this (or any other) example.

2.21

i. System diagram.



ii. Linear momentum is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of the collision between the tennis ball and the tennis racket.

v. The system is closed. Energy passes into the system, but no mass enters the system through bulk transfer.

vi. The system is in steady-state since all linear momentum that begins in the system is still present after the collision.

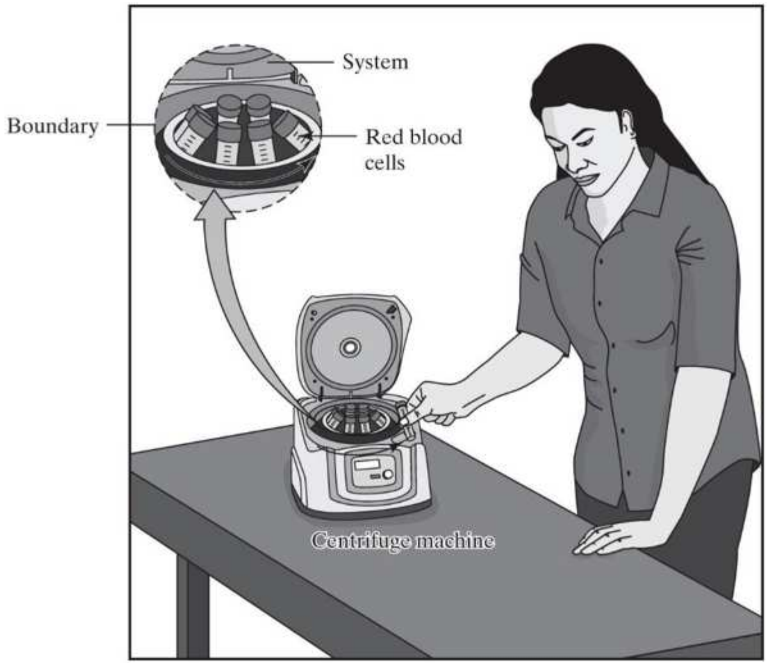
vii. The system is non-reacting – no chemical reactions or energy interconversions occur.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

ix. Linear momentum is a conserved property. It is neither generated nor consumed in this example.

2.22

i. System diagram.



ii. Angular momentum is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the time necessary for centrifugation to occur.

v. The system is open since mass enters the system through bulk transfer.

vi. The system is in steady-state since all momentum that begins in the system is still present after centrifugation.

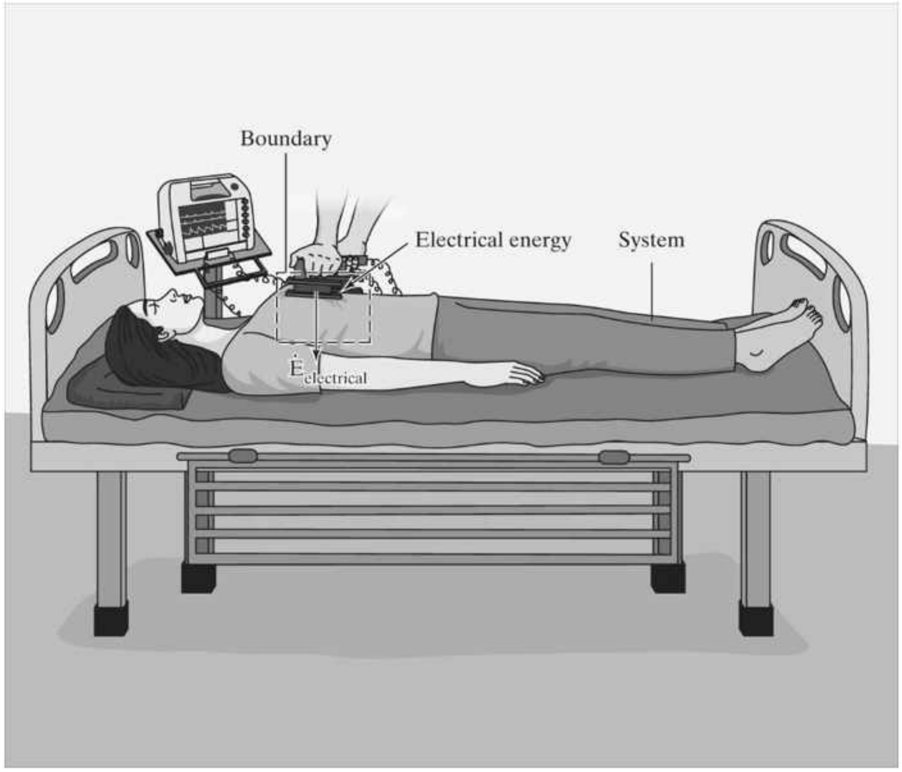
vii. The system is non-reacting – no chemical reactions or energy interconversions occur.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

ix. Angular momentum is a conserved property. It is neither generated nor consumed in this example.

2.23

i. System diagram.



ii. The rate of electrical energy travel is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of defibrillation, which is approximately 0.3 seconds.

v. The system is closed. Electrical energy enters the system through direct contact, but there is no bulk transfer of mass.

vi. The system is dynamic since the patient's chest is accumulating electrical energy.

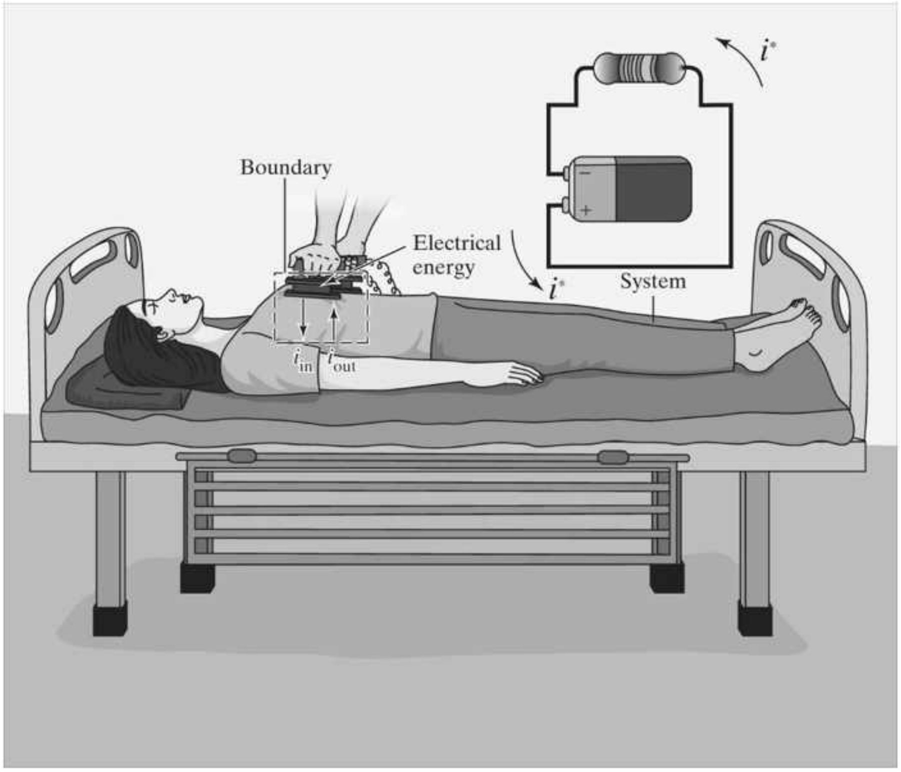
vii. The system is non-reacting, but energy interconversions occur (electrical energy is converted into heat energy).

viii. A differential equation best describes the system as it incorporates rates. An integral equation can also describe the system if a finite time interval is given.

ix. The system consumes electrical energy as it is converted into heat energy, thus it is not conserved.

2.24

i. System diagram.



ii. The rate of charge movement, or current, is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of defibrillation, which is approximately 0.3 seconds.

v. The system is closed. Charge enters the system via direct contact with the body, but there is no bulk transfer of mass.

vi. The system is in steady-state since there is no accumulation of charge. The current passes through the chest and returns to the defibrillator pads.

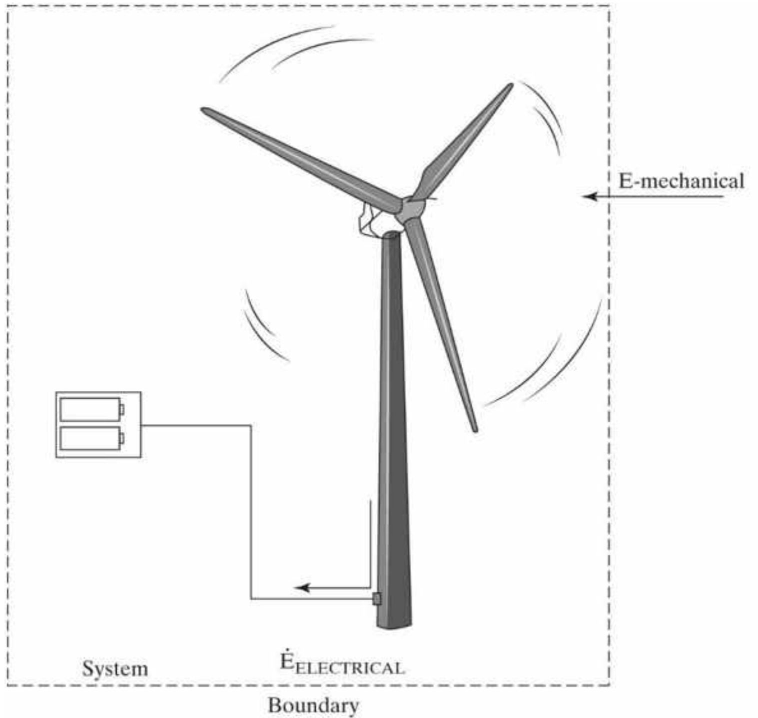
vii. The system is non-reacting, and there are no energy interconversions occurring in the system.

viii. A differential equation best describes the system since it incorporates rates. An integral equation can also describe the system if a finite time interval is given.

ix. Since charge is not being consumed or generated in the system (i.e. the patient's chest), it is conserved.

2.25

i. System diagram.



ii. Total energy is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is 8 hours.

v. The system is closed. Energy is entering the system, but no mass is entering the system via bulk transfer.

vi. The system is dynamic since energy from an external source is accumulating in the system.

vii. The system is non-reacting. Though total energy remains the same throughout the system, mechanical energy is being converted into electrical energy.

viii. An integral equation best describes the system since it incorporates rates and a finite time period.

ix. Total energy cannot be generated not consumed; the mechanical energy is being converted into electrical energy.

2.26

i. System diagram.

ii. The rate of charge movement is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of time it takes to walk across the rug and touch the door handle.

v. The system is open. Energy is entering the system.

vi. The system is dynamic since the amount of charge in the body is not constant. Charge accumulates as the subject walks across the room and is discharged when the subject touches the door handle. Since the total amount gained and lost is not explicitly stated, a steady-state system cannot be assumed.

vii. The system is non-reacting, but mechanical energy is converted to electrical energy.

viii. An integral equation best describes the system since it incorporates rates and a defined time interval (time of defibrillation).

ix. Total charge is always conserved.

2.27

i. System diagram.

ii. Linear momentum is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the time necessary to bring the baseball to a complete stop.

v. The system is closed. Linear momentum passes across the system boundary, but no mass enters the system through bulk transfer.

vi. The system is dynamic since the linear momentum of the glove increases as the catcher's hand moves backwards upon impact.

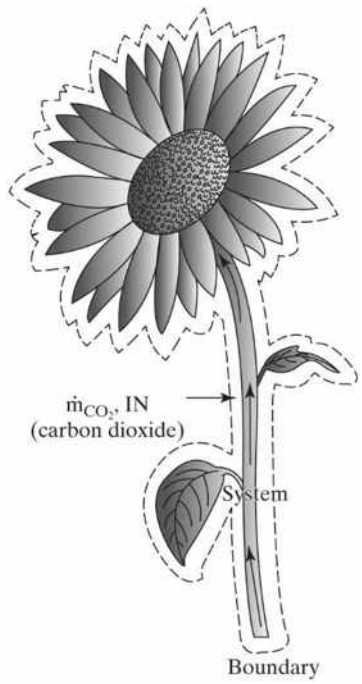
vii. The system is non-reacting, and no energy interconversions occur.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

ix. Linear momentum is a conserved property. It is neither generated nor consumed in this example.

2.28

i. System diagram.



ii. The rate of travel of the carbon dioxide mass is an extensive property of the system.

iii. See above diagram.

iv. No time period is explicitly stated. Since rates are being studied, assume a continuous, ongoing time period that encompasses the length of time that photosynthesis occurs.

v. The system is open since mass comes into the system through bulk transfer.

vi. The system is dynamic – carbon dioxide in the plant changes over time based on rates of photosynthesis and cellular respiration.

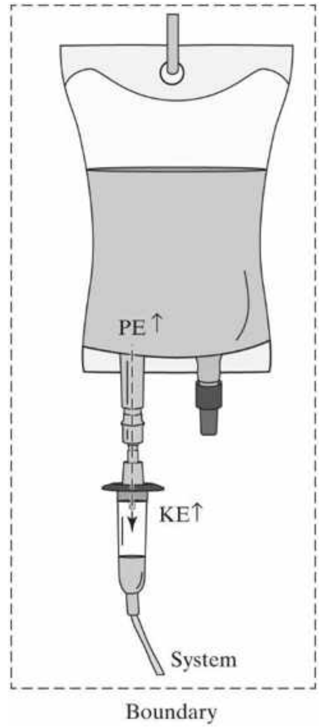
vii. The system is reacting since carbon dioxide is converted to oxygen during photosynthesis.

viii. A differential equation best describes the system as it incorporates rates and a continuous time period.

ix. Carbon dioxide is not conserved since it is both generated and consumed by the plant.

2.29

i. System diagram.



ii. Total energy is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the time necessary for the drop to reach the tube.

v. The system is closed since no mass enters the system through bulk transfer.

vi. The system is in steady-state since all total energy is conserved and remains in the system.

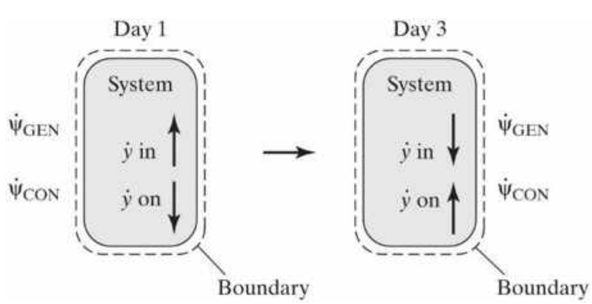
vii. The system is non-reacting and no energy interconversions occur.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

ix. Total energy is conserved since it is neither generated nor consumed.

2.30

i. System diagram.



ii. The rate of cell growth is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is 3 days.

v. The system is closed since no mass enters or leaves the system through bulk transfer.

vi. The system is dynamic since the rate of cell growth changes over time.

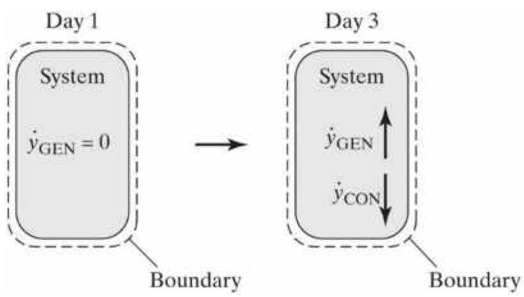
vii. The system is reacting since the cell interaction with the yeast causes cell death.

viii. An integral equation best describes the system as it incorporates rates and a finite time period.

ix. Cells are not conserved as they are being generated and consumed through proliferation and death, respectively.

2.31

i. System diagram.



ii. The rate of yeast cell growth is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is 3 days.

v. The system is closed since no mass enters or leaves the system through bulk transfer.

vi. The system is dynamic since the rate of cell growth changes over time.

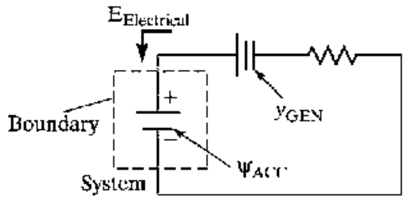
vii. The system is reacting since the cell interaction with the yeast causes cell death.

viii. An integral equation best describes the system as it incorporates rates and a finite time period.

ix. Cells are not conserved as they are being generated and consumed through proliferation and death, respectively.

2.32

i. System diagram.



ii. Electrical energy is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the amount of time it takes for the capacitor to become fully charged.

v. The system is closed. No mass enters of leaves the system through bulk transport.

vi. The system is dynamic since electrical energy is increasing.

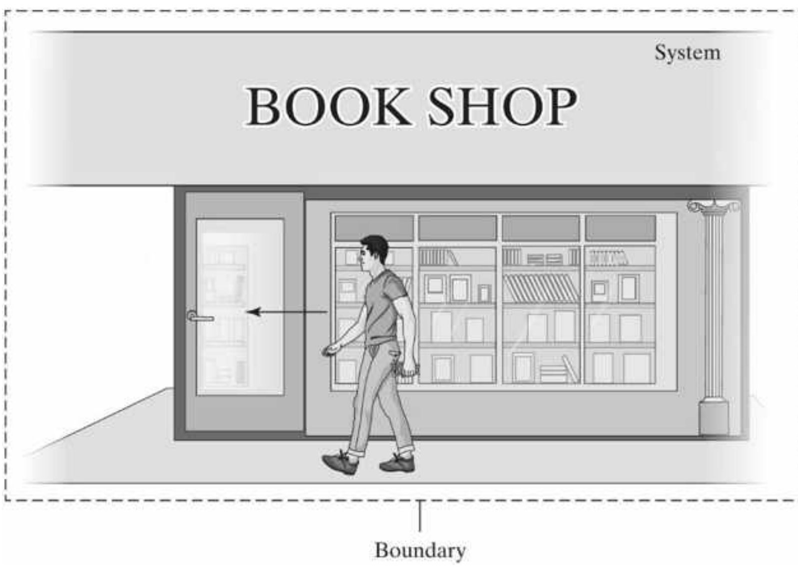
vii. The system is non-reacting, and no energy interconversions occur.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

ix. Electrical energy is not conserved since it is being generated as the terminals depolarize.

2.33

i. System diagram.



ii. Money is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is one school year.

v. The system is open. Money enters and leaves the system through bulk transport.

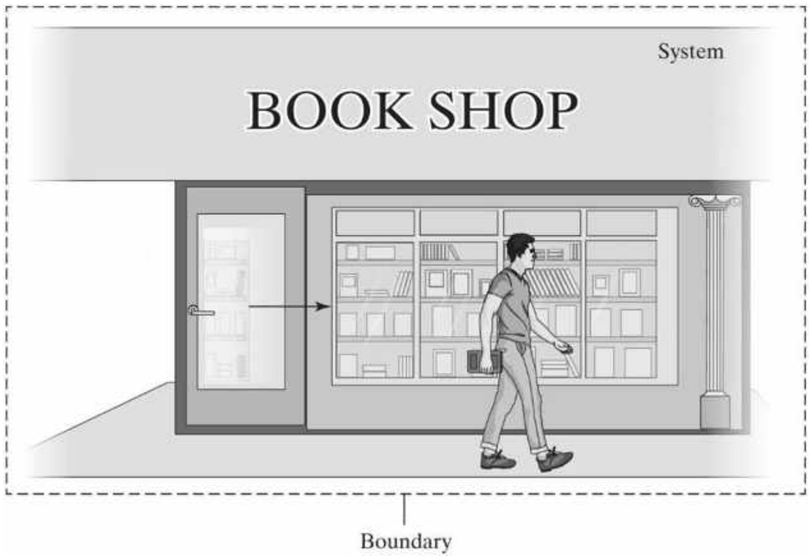
vi. The system is dynamic since the amount of money in the system changes over time.

vii. The system is non-reacting, and no energy interconversions occurs.

viii. An algebraic equation best describes the system as it incorporates discrete quantities.

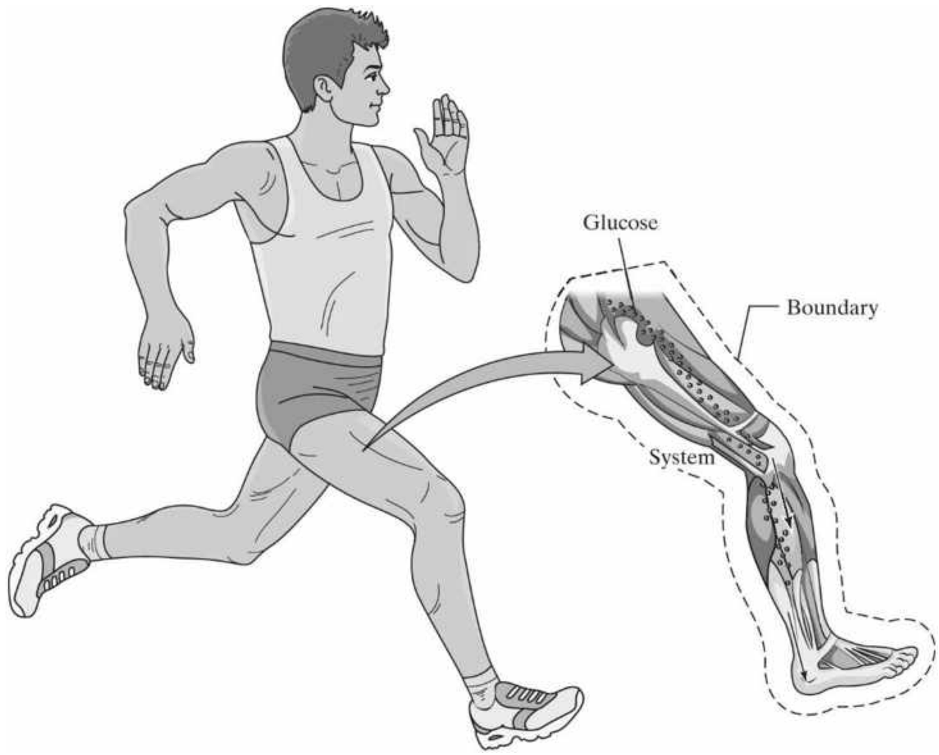
ix. Money is not generated or consumed in the system and is therefore conserved.

Bookstore stock can be modeled similarly in this system.



2.34

i. System diagram.



ii. Glucose is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the length of the race.

v. The system is open. Glucose enters and leaves the system.

vi. The system is dynamic since carbon dioxide and lactate will accumulate in the thigh muscle. The rate of metabolism will also change during the race. A "snapshot" of the muscle at the beginning of the race will not resemble that of the muscle at the end of the race.

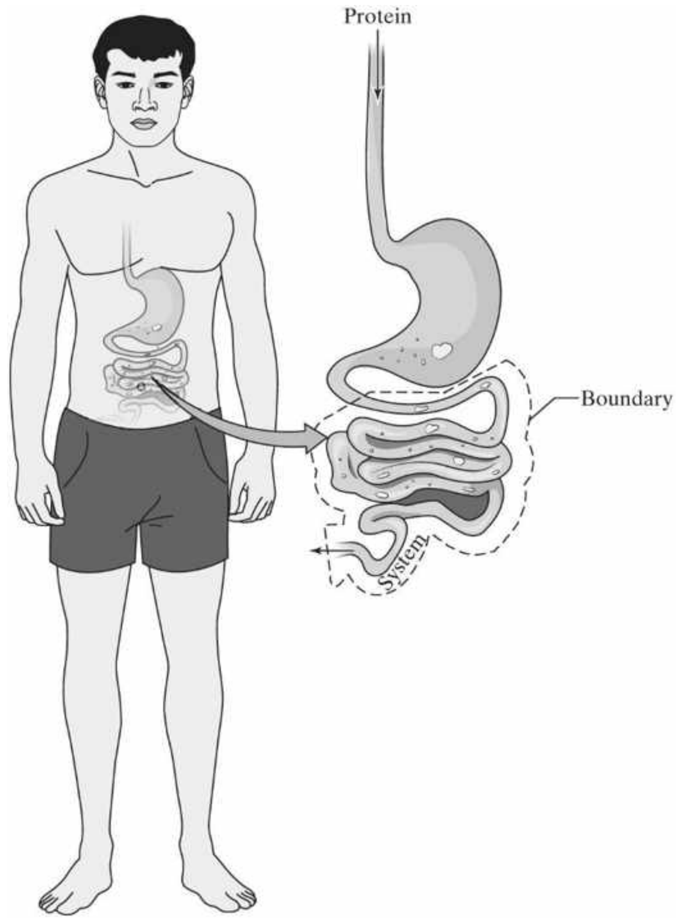
vii. The system is reacting – glucose and oxygen are metabolized to carbon dioxide and lactate.

viii. An integral equation best describes the system as it incorporates rates and a finite time period.

ix. Electrical energy is not conserved in the capacitor.

2.35

i. System diagram.



ii. Protein is an extensive property of the system.

iii. See above diagram.

iv. The time period of interest is the 4 hours following the start of dinner.

v. The system is open. Protein enters the small intestine through the stomach and exits through the walls of the small intestine to the large intestine.

vi. The system is dynamic – as the protein moves through the stomach and small intestine, it changes in chemical composition. At the beginning of the system monitoring, there likely is nothing in the system, and at the end of monitoring, the system likely is full.

vii. The system is reacting since enzymes help break down the protein into peptides.

viii. An integral equation best describes the system as it incorporates the rate of digestion and a finite time period.

ix. Protein is not conserved in the system since it is being consumed.

2.36

Extensive properties that are always conserved are total mass, total moles, mass and moles of individual elements, total energy, net charge, linear momentum, and angular momentum.

2.37

The time scale frames the activities of the extensive property within the system. Oftentimes, a shorter time period indicates a dynamic system, and a longer time period frequently (but not always) indicates a steady-state system. In a dynamic system, the extensive property changes over the time period, but in a steady-state system, the extensive property does not vary greatly with time. Consider the food entering and leaving a house over a period of 24 hours. Food may enter the system in the form of a week's worth of purchased groceries and exit in the form of 1 day's waste, but the quantities are likely unequal, i.e. a dynamic system. However, when considering the system over the period of 1 year, the amount food entering the system and exiting the system is roughly equal, representing a steady-state system.

2.38

a) Property: Water

Label: See figure.

Time period: 1 day

Open/Closed: The system is open since material (solids) is moving in and out of the system (the human body).

Reacting/Non-Reacting: The system is reacting since the solids are converted to water and energy within the body.

Steady-State/Dynamic: The system is dynamic – if the person is gaining weight, snapshots of the body over time do not look similar.

ψ_{IN} : 432g (food)

Total ψ_{IN} : 432g

ψ_{OUT} : 12g (urine), 70g (feces)

Total ψ_{OUT} : 82g

$$\psi_{IN} - \psi_{OUT} + \psi_{GEN} + \psi_{CON} = \psi_{ACC}$$

Some of the solids are being converted into energy, water, or other substances. Some of the solids may be accumulating in the body (i.e. the person is gaining weight).

b) Property: Water

Label: See figure.

Time period: 1 day

Open/Closed: The system is open since water is moving in and out of the body.

Reacting/Non-Reacting: The system is reacting due to the metabolic production of water in the body

Steady-State/Dynamic: It is not sure whether the system can be classified steady-state or dynamic. There is no accumulation, which suggests a steady-state system, but snapshots over time (but within one day) do not look similar.

$\psi_{IN} - \psi_{OUT} + \psi_{GEN} + \psi_{CON} = \psi_{ACC}$

ψ_{IN} : $1000g$ (food) + $1200g$ (drinking water) + $50g$ (air)

$\psi_{IN} = 2250g$

ψ_{OUT} : $350g$ (lost through skin) + $400g$ (air) + $200g$ (sweat) + $1400g$ (urine) + $200g$ (feces)

$\psi_{OUT} : 2550g$

$\psi_{GEN} : 300g$ (metabolism)

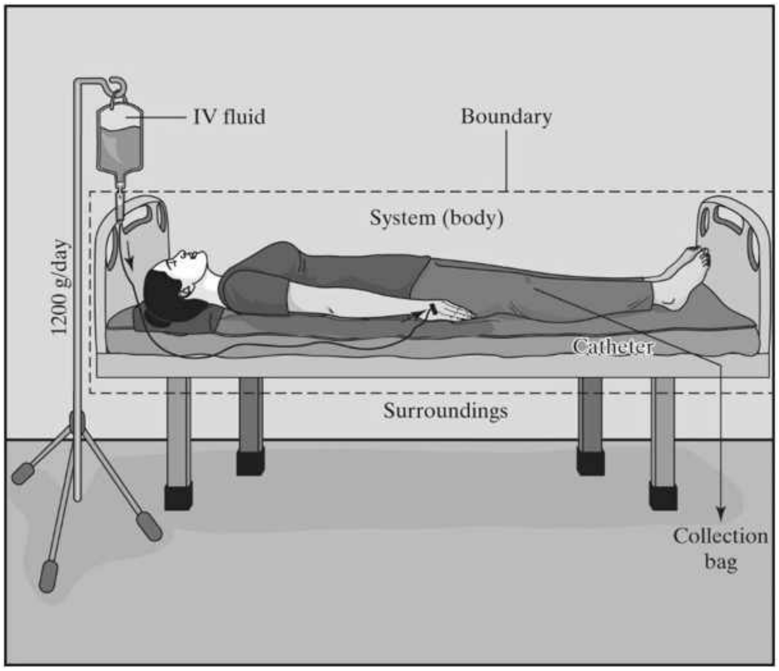
$2250g - 2550g + 300g - 0 = \psi_{ACC}$

$\psi_{ACC} = 0$

Yes, all the water is accounted for.

Looking at the water balance on a day-to-day basis, the person can probably be described to be in steady-state.

2.39 A schematic of the patient is shown below:



Open/Closed: Since there is an inlet (IV drip) of 1200 g/day and outlet (urine collected in catheter) of 1600 g/day, the system is open.

Steady-State/Dynamic: The system is steady-state since the mass of the patient's body does not change with time. Estimating the weight loss if there was an accumulation term:

$$400g\left(2.2\frac{lb_m}{kg}\right)\left(\frac{1kg}{1000g}\right)\times 7day = 6.2lb_m$$

A hospital scale should be able to pick up a change in weight of 6.2 lb_m.

Reacting/Non-Reacting: Since the problem statement says there are no additional inlets or outlets, the "missing" water is not another stream. Looking at the Accounting Equation,

$$\dot{\psi}_{IN} - \dot{\psi}_{OUT} + \dot{\psi}_{GEN} + \dot{\psi}_{CON} = \dot{\psi}_{ACC} = \frac{d\psi}{dt}$$

the "missing" water could come from a generation (or consumption) term. It can be assumed that the system is reacting.

Talking with the doctor, you discover that "normal" metabolism of foodstuffs generates 300-500 g/day of water (Cooney 1976, standard physiology books). Give this information, you surmise that the patient generates 400 g/day of water through metabolism.

Since mass flow rates of water are given, the differential accounting equation is most appropriate. It is reduced appropriately as follows: $\dot{\psi}_{IN} - \dot{\psi}_{OUT} + \dot{\psi}_{GEN} = 0$.

2.40 See Table 2.5 for the list of breakfast, lunch, and dinner foods.

a) $m = \sum m_S$

Breakfast: $200g$ (oatmeal) + $75g$ (milk) + $225g$ (orange) = $500g$

Lunch: $100g$ (apple) + $100g$ (bread) + $90g$ (bacon) + $40g$ (cheese) = $330g$

Dinner: $350g$ (pork) + $150g$ (asparagus) + $150g$ (potatoes) + $50g$ (bread) = $700g$

$m = 500g + 330g + 700g = 1530g$

$m_{solid} = 0.3m = 0.3(1530g) = 459g$ solid intake

$m_{water} = 0.7m = 0.7(1530g) = 1071g$ water intake

From **Problem 2.38**, as the overall intake of the average man (2250g) is larger than Joe's overall intake (1530g), the solid intake of the average man (1000g) is greater than Joe's solid intake (459g), and the water intake of the average man (1200g) is also greater than Joe's water intake (1071g). The solids content of the average man is 44.4% of the overall intake compared to Joe's 30%, and the water content of the average man is 53.3% of the overall intake compared to Joe's 70%.

b) See table below (columns B, C, D, F, G, I, J) for full calculations.

Oatmeal: 14.2% protein, 7.4% fat, 68.2% carbohydrates (from Table 1, Guyton & Hall Textbook of Medical Physiology).

$$\text{mass} = \frac{(\text{mass percent})(\text{total mass})}{100} = \frac{(wt\%)m}{100}$$

Protein: $m_P = \frac{(14.2)(200g)}{100} = 28.4g$

Fat: $m_F = \frac{(7.4)(200g)}{100} = 14.8g$

Carbs: $m_C = \frac{(68.2)(200g)}{100} = 136.4g$

Totals: $138g$ protein; $195g$ fat; $294g$ carbohydrates

c) See table below (columns L, M) for full calculations.

$$\text{Energy} = \frac{\text{calories}}{100\text{g}} \times \text{mass}$$

$$E_{oatmeal} = \left(\frac{396cal}{100g}\right)(200g) = 792cal$$

Total energy: 3475 cal

d) See table below (columns D, E, G, H, J, K) for full calculations.

$$\text{Energy from component} = (\#\ \text{grams of component})\left(\frac{\text{Energy}}{\#\ \text{grams of component}}\right)$$

For oatmeal:

$$E_{protein} = 28.4g\left(4\frac{cal}{g}\right) = 113.6cal$$

$$E_{fat} = 14.8g\left(9\frac{cal}{g}\right) = 133.2cal$$

$$E_{carbs} = 136.4g\left(4\frac{cal}{g}\right) = 545.6cal$$

Totals: $553.2cal$ protein; $1758.1cal$ fat; $1177.8cal$ carbs

Round to 2-3 significant figures: $550cal$ protein; $1760cal$ fat; $1180cal$ carbs

Total: 3490 cal

$\%\ \text{protein} = \frac{550cal}{3490cal}(100) = 16\%$ compared to 15% average: Joe is similar compared to the average.

$\%\ \text{fat} = \frac{1760cal}{3490cal}(100) = 50\%$ compared to 40% average: Joe is high compared to the average.

$\%\ \text{carbs} = \frac{1180cal}{3490cal}(100) = 34\%$: compared to 45% average: Joe is low compared to the average.

e) Energy from part (c): 3475 cal

Energy from part (d): 3490 cal

At an engineering approximation, these values are the same.

Note: Data from the Guyton and Hall textbook usually has 3 significant figures and the tenths place specified. Answers should be 3 significant figures and/or the tenths place should be specified. (Five significant figures are too many. E.g. 1758.1 cal should be rounded.)

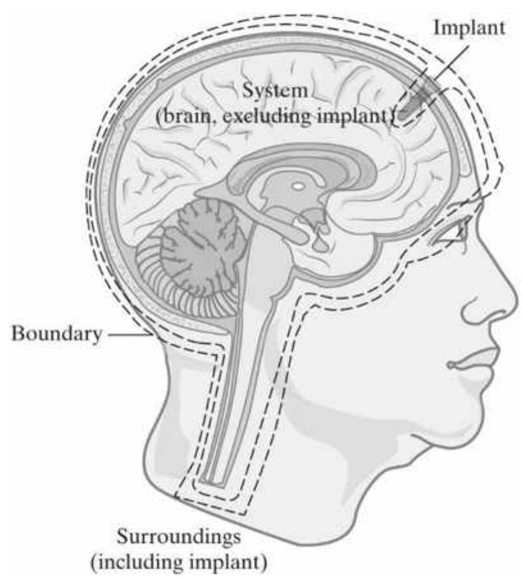
A	B	C	D	E	F	G	H	I	J	K	L	M
food type	food eaten (g)	% protein	protein (g)	energy from protein (cal)	% fat	fat (g)	energy from fat (cal)	% carbs	carbs (g)	energy from carbo (cal)	energy/100g (cal)	energy (cal)
oatmeal	200	14.2	28.4	113.6	7.4	14.8	133.2	68.2	136.4	545.6	396	792
milk	75	3.5	2.6	10.5	3.9	2.9	26.3	4.9	3.7	14.7	69	52
orange	225	0.9	2.0	8.1	0.2	0.5	4.1	11.2	25.2	100.8	50	113
bread	100	9.0	9.0	36.0	3.6	3.6	32.4	49.8	49.8	199.2	268	268
apple	100	0.2	0.2	0.8	0.4	0.4	3.6	14.9	14.9	59.6	64	64
cheese	40	23.9	9.6	38.2	32.3	12.9	116.3	1.7	0.7	2.7	393	157
bacon, broiled	90	25.0	22.5	90.0	55.0	49.5	445.5	1.0	0.9	3.6	599	539
pork	350	15.2	53.2	212.8	31.0	108.5	976.5	1.0	3.5	14.0	340	1190
potatoes	150	2.0	3.0	12.0	0.1	0.2	1.4	19.1	28.7	114.6	85	128
asparagus	150	2.2	3.3	13.2	0.2	0.3	2.7	3.9	5.9	23.4	26	39
bread	50	9.0	4.5	18.0	3.6	1.8	16.2	49.8	24.9	99.6	268	134
total	1530		138	553		195	1758		294	1178		3475
fraction of total energy				0.16			0.51			0.34		

mass sum from protein, fat, carbs: 628 g
energy estimate using protein, fat, carbs: 3489 cal

Note: Some students may add water and/or milk to the dry oatmeal.
Note: Some students may use a different value for bacon.

2.41

a) Consider the system to be the entire brain, excluding the implant.



$$\dot{m}_{IN} - \dot{m}_{OUT} + \dot{m}_{GEN} - \dot{m}_{CON} = \dot{m}_{ACC}$$

Since none of the NGF is leaving the brain, the equation can be rewritten to look like:

$$\dot{m}_{IN} + \dot{m}_{GEN} - \dot{m}_{CON} = \dot{m}_{ACC}$$

$$\dot{m}_{IN} = 0.24 \frac{\mu g \text{ NGF}}{day}$$

$$\dot{m}_{CON} = 0.11 \frac{\mu g \text{ NGF}}{day},\ 0.023 \frac{\mu g \text{ NGF}}{day}$$

$\dot{m}_{GEN} =$ This term may exist since brain makes NGF.

$\dot{m}_{ACC} =$ This terms is likely present.

b) Assume $\dot{m}_{GEN} = 0$.

$$0.24 \frac{\mu g \text{ NGF}}{day} - (0.11 + 0.023) \frac{\mu g \text{ NGF}}{day} = \dot{m}_{ACC}$$

$$\dot{m}_{ACC} = 0.107 \frac{\mu g \text{ NGF}}{day}$$

$$\frac{0.107 \frac{\mu g \text{ NGF}}{day} \times (x\ day)}{1400 cm^3} = 2.0 \frac{ng}{mL} \left(\frac{10^6 \mu g}{10^9 ng} \right)$$

$$x = 26\ days$$

c)

$$\frac{0.107 \frac{\mu g \text{ NGF}}{day} \times (x\ day)}{400 cm^3} = 5.0 \frac{ng}{mL} \left(\frac{10^6 \mu g}{10^9 ng} \right)$$

$$x = 18.7\ days$$