MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Departments of Electrical Engineering, Mechanical Engineering, and the Harvard-MIT Division of Health Sciences and Technology

6.022J/2.792J/BEH.371J/HST542J: Quantitative Physiology: Organ Transport Systems

QUIZ 1

Tuesday, March 2, 2004

Name: ________________________________

Problem 1

A. Draw normal $P(t)$ waveforms for the left ventricle, left atrium, and aorta. Show two complete cardiac cycles, and use typical normal values for the pressures. Use the time axis provided in Figure 1.1a, and assume a heart rate of 60 bpm.

B. The cardiac output was measured using the Fick method.

Oxygen uptake	363 ml O_2 per minute
Arterial oxygen content	200 ml O_2 per liter of blood
Mixed venous oxygen content	145 ml O_2 per liter of blood

Using this data together with your $P(t)$ waveforms, draw the corresponding P-V loop for the LV. Assume an end-diastolic LV volume of 170 cc., and a LV "dead" volume of 15 cc for both systole and diastole. Draw linear systolic and diastolic P-V curves, and use the axes provided.

C. Correlate the following landmarks on the P-V loop with the appropriate points on the $P(t)$ curves using the numeric labels below:

a: begin LV contraction

b: peak LV pressure

c: begin LV filling

d: end ejection

e: begin LV ejection

D. "Ejection fraction" (EF) is defined as the percentage of the end-diastolic volume that is ejected during systole. What is the EF in this case? (Normal $>$ 55%.)

E. A papillary muscle in the LV ruptures. (Assume that there are no functioning controls, and that the system has reached a new steady state.) The new arterial BP (systolic, diastolic, and mean) drops to 60% of its original value.

(i) Sketch two cardiac cycles showing the new $P(t)$ waveforms, using the axes supplied in Figure 1.1b. Pay particular attention to the new amplitudes of the LV and LA pressures. Assume no change in the left ventricular end-diastolic pressure and volume.

(ii) Sketch the new P-V loop on the same axes as part (B) above. Estimate the new stroke volume.

(iii) What is the new ejection fraction (using the definition in part D)?

(iv) Crudely approximate the stroke volume delivered to the aorta by making use of the Windkessel approximation.

(v) What is the "forward ejection fraction" (the percentage of the end-diastolic LV volume that is ejected into the aorta)?

(vi) As a result of the papillary muscle rupture, a murmur appears. Indicate its temporal location on the time axis provided in Figure 1.1.

Figure 1.1:

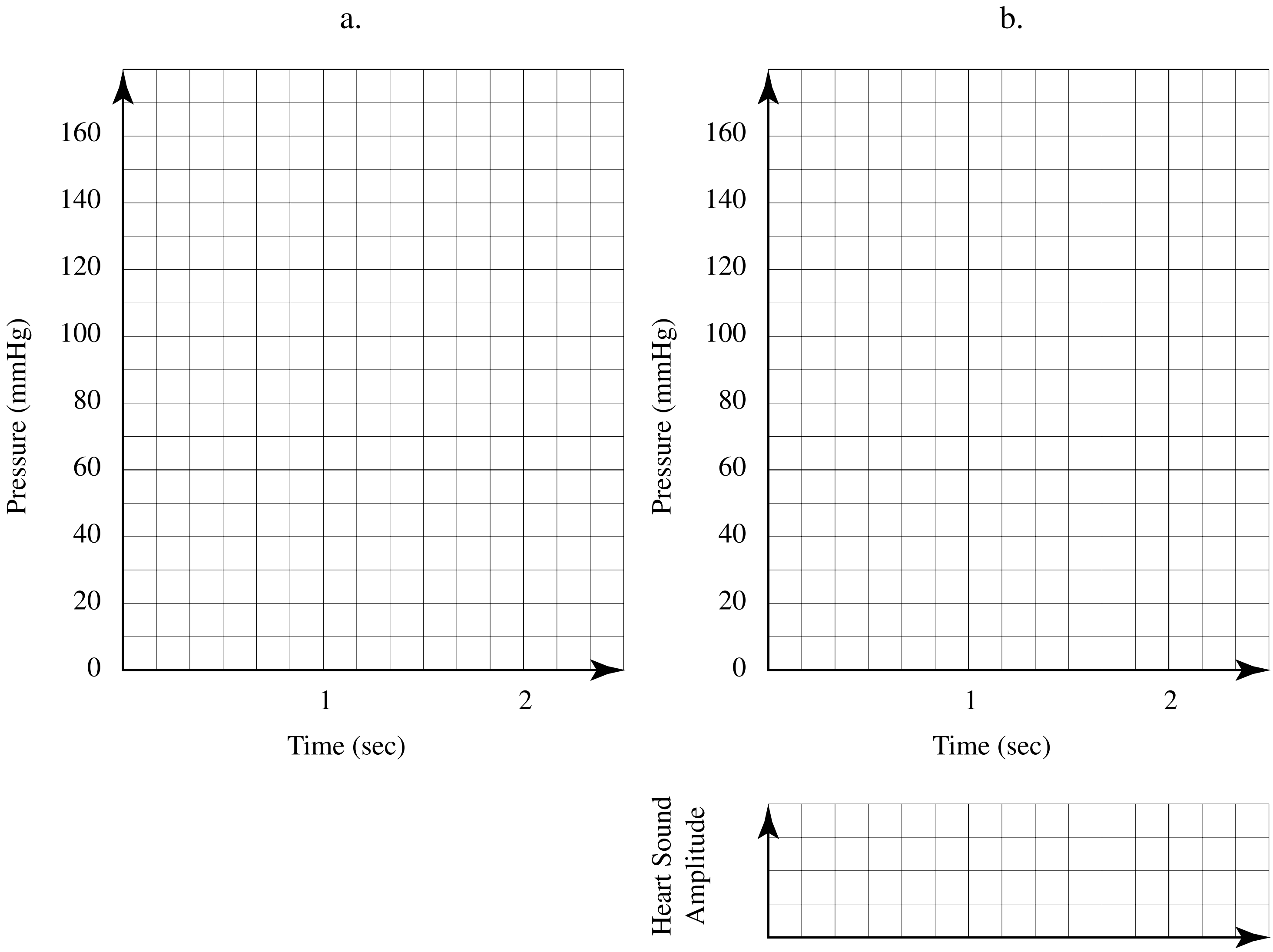
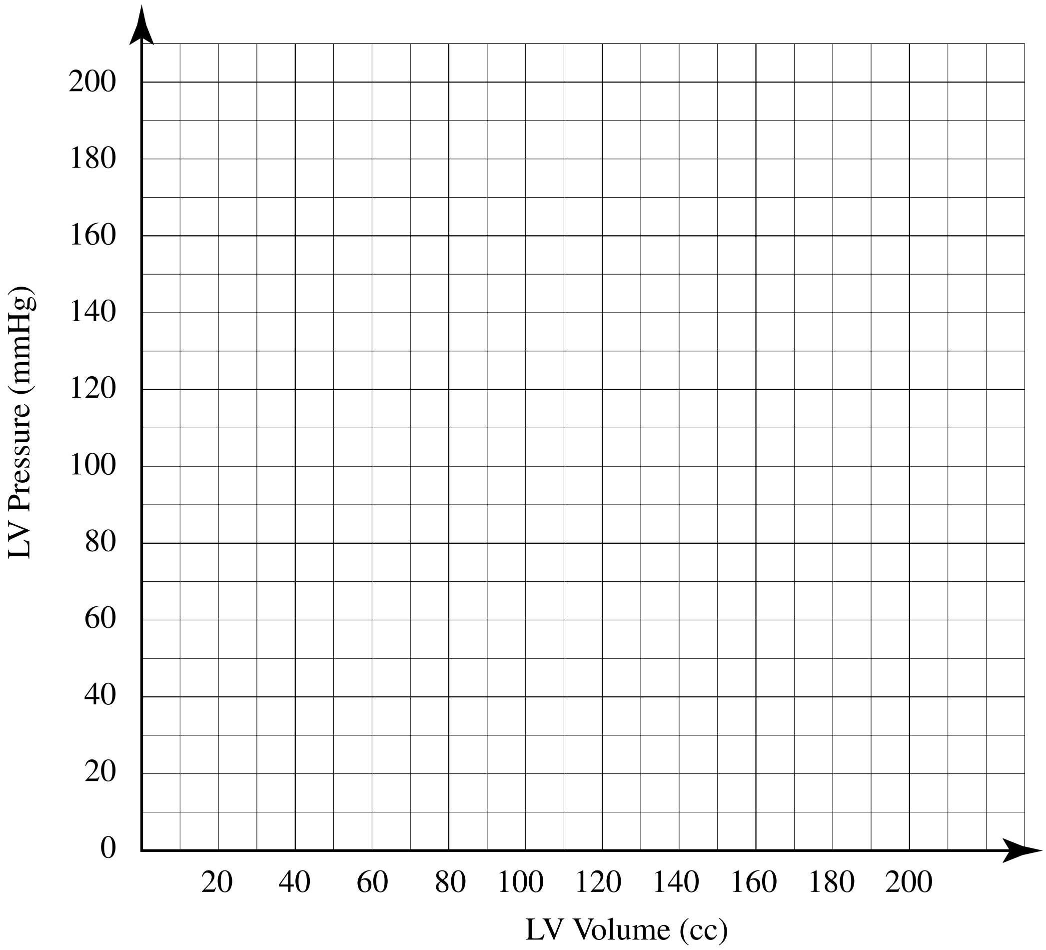

a.
b.
160
140
120
100
80
60
40
20
0
1
2
Pressure (mmHg)
Time (sec)
Heart Sound
Amplitude

Figure 1.2:



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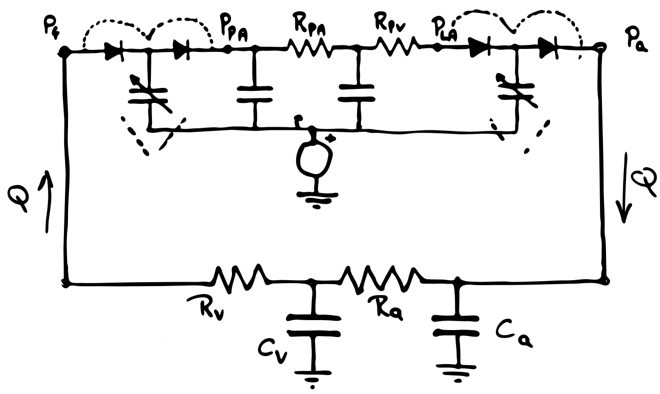
Problem 2

We have used the lumped parameter model of the cardiovascular system that is shown in Figure 2.1. The following relationship was derived to relate cardiac output to the various model parameters (in operating region I):

$$\text{C.O.} = \frac{P_{ms} - P_{th} - \left(P_{PA}^{0} - P_{th}\right)\frac{C_S^r}{C_D^r}}{R_v + R_a\frac{C_a}{C_a + C_v} + \frac{1}{f C_D^r}}$$

Figure 2.1: Lumped Parameter Model



Part 1

Using this expression and/or graphical analysis explain the expected changes in: (a) *cardiac output*, (b) *arterial blood pressure*, and (c) *pulse pressure* that would result from the following interventions, assuming an uncontrolled CV system and a heart rate of 60 bpm.

A. Increasing the peripheral resistance, R_a.

B. Decreasing total blood volume.

C. Increasing left ventricular contractility.

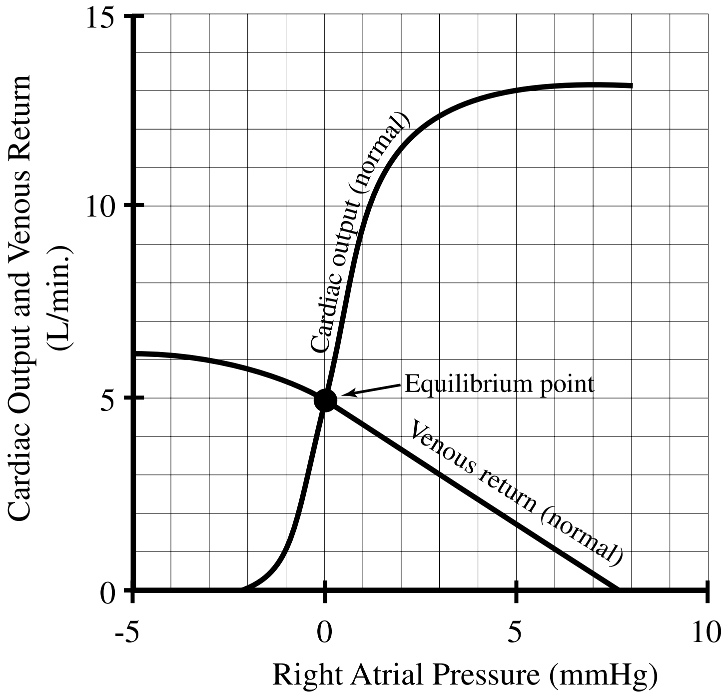
D. Decreasing arterial capacitance, C_a, by a factor of two.

E. Increasing the intra-thoracic pressure by 10 mmHg, and P_{ms} by 8 mmHg by blowing into a balloon.

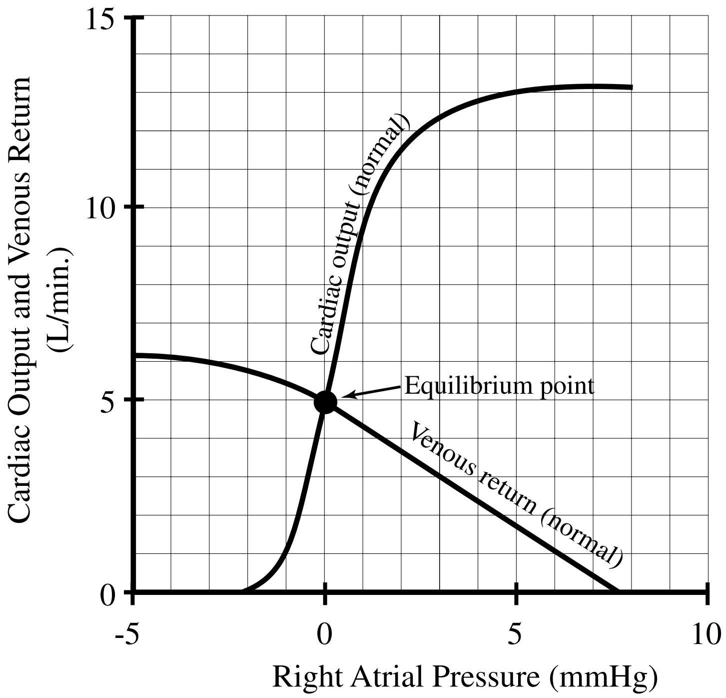
Part 2

For each intervention above, sketch the expected qualitative changes in the CO/VR curves using the graphs below.

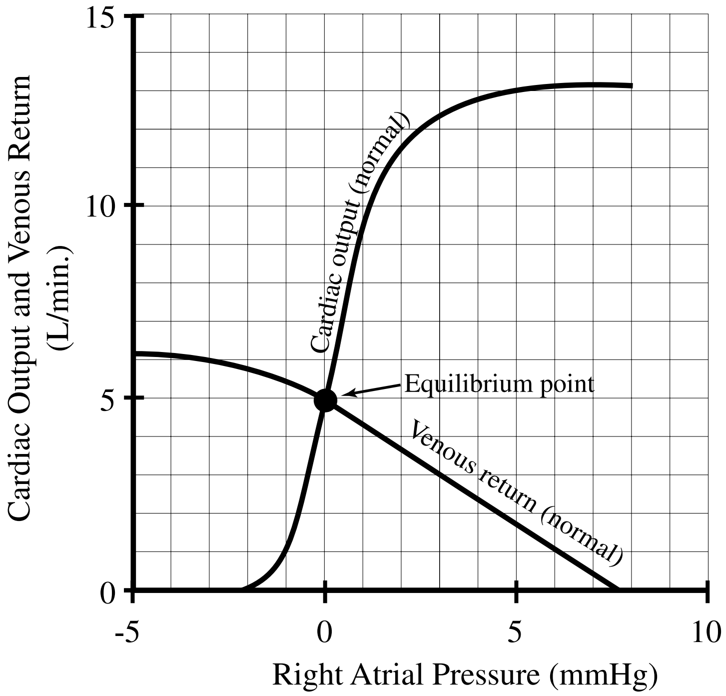
A. Increasing the peripheral resistance, R_a.



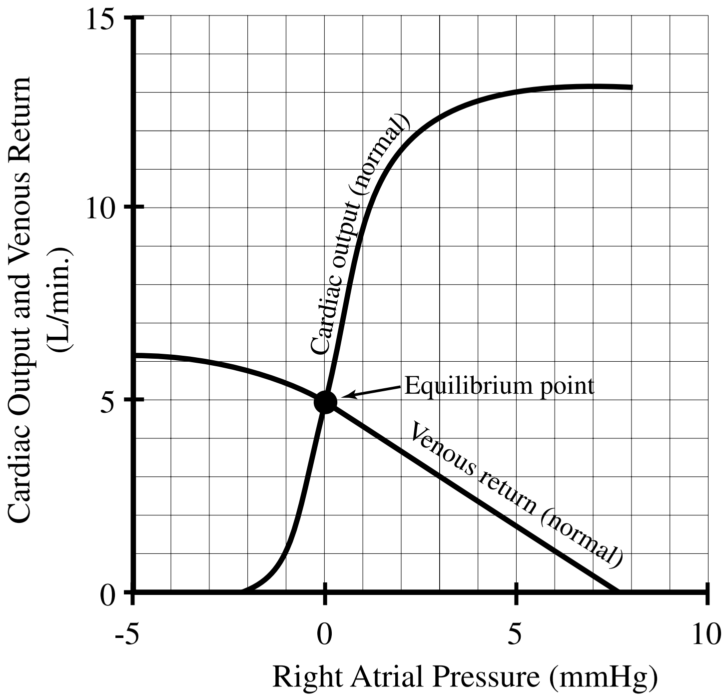
B. Decreasing total blood volume.



C. Increasing left ventricular contractility.



D. Decreasing arterial capacitance, C_a, by a factor of two.



E. Increasing the intra-thoracic pressure by 10 mmHg, and P_{ms} by 8 mmHg by blowing into a balloon.

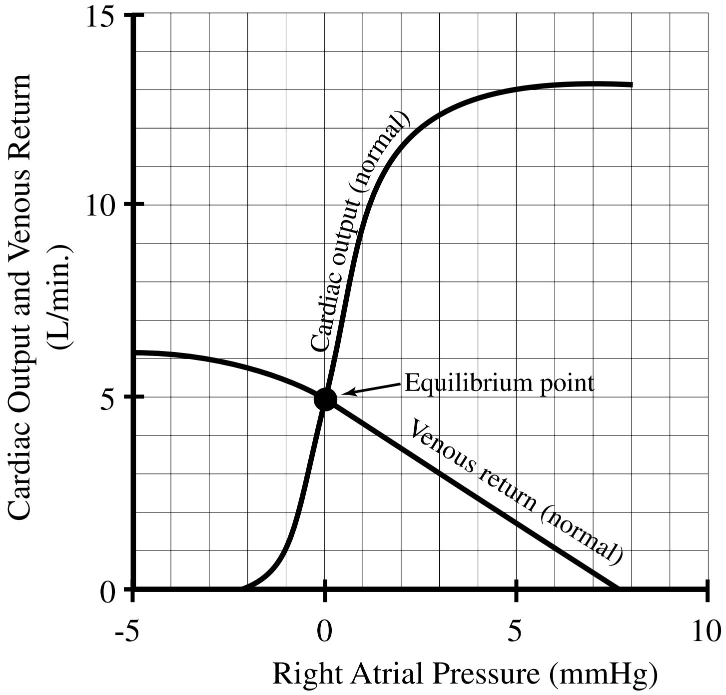


Table 1: Glossary of Symbols and Nominal Value for Model Parameters

Symbol	**Definition**	**Normal Value**
ΔV	stroke volume	96 cc
$f = \frac{1}{T}$	heart rate	60/min. = 1/sec.
$T = T_S + T_D$	duration of heart cycle	1 sec.
T_S	duration of systole	.3 sec.
T_D	duration of diastole	.7 sec.
C_D^r	diastolic capacitance of RV	20 ml/mmHg
C_D^l	diastolic capacitance of LV	10 ml/mmHg
C_S^r	minimum systolic capacitance of RV	2 ml/mmHg
C_S^l	minimum systolic capacitance of LV	.4 ml/mmHg
$V_{\max}^r$, $V_{\max}^l$	"maximum" volumes, RV, LV	200 cc
$V_T = V + V_0$	total volume of blood in peripheral vasculature	4000 ml
V_0	volume needed to fill peripheral vasculature without increasing pressure	3200 ml
C_a	arterial capacitance	2 ml/mmHg
C_v	venous capacitance	100 ml/mmHg
R_a	arterial resistance	1 mlHg/(ml/sec)
R_v	resistance to venous return	.05 mmHg/(ml/sec)
P_{th}	mean intrathoracic pressure	-5 mmHg
P_A^0	pulmonary artery pressure (end-systolic) referenced to mean intrathoracic pressure	15 mmHg
P_{ms}	mean systemic filling pressure (see text)	7.8 mmHg
P_v	peripheral venous pressure	6.1 mmHg

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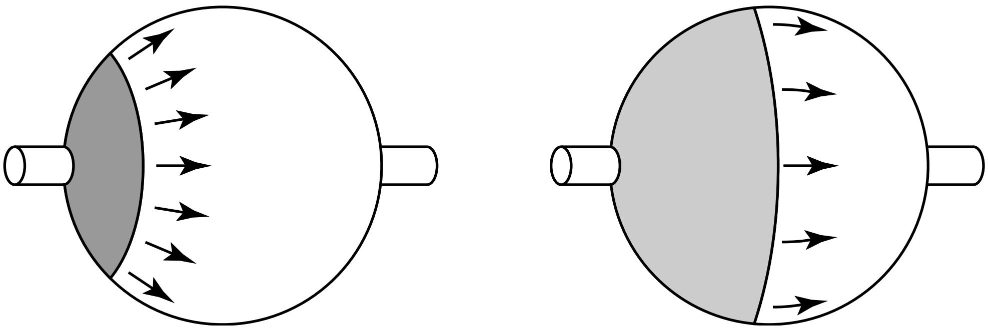
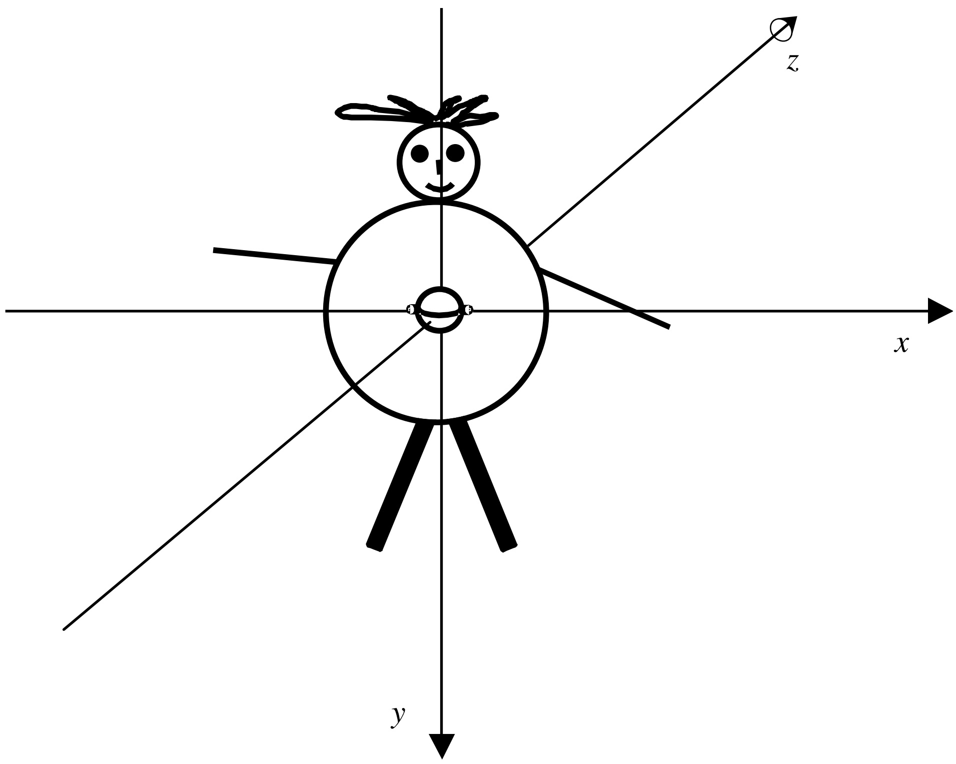
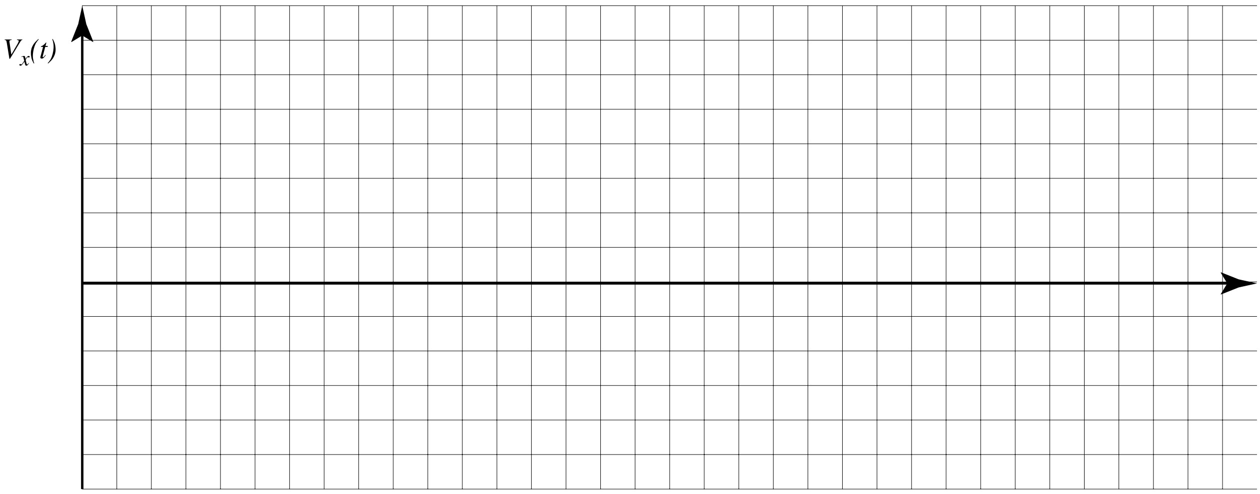
Figure 3.3:

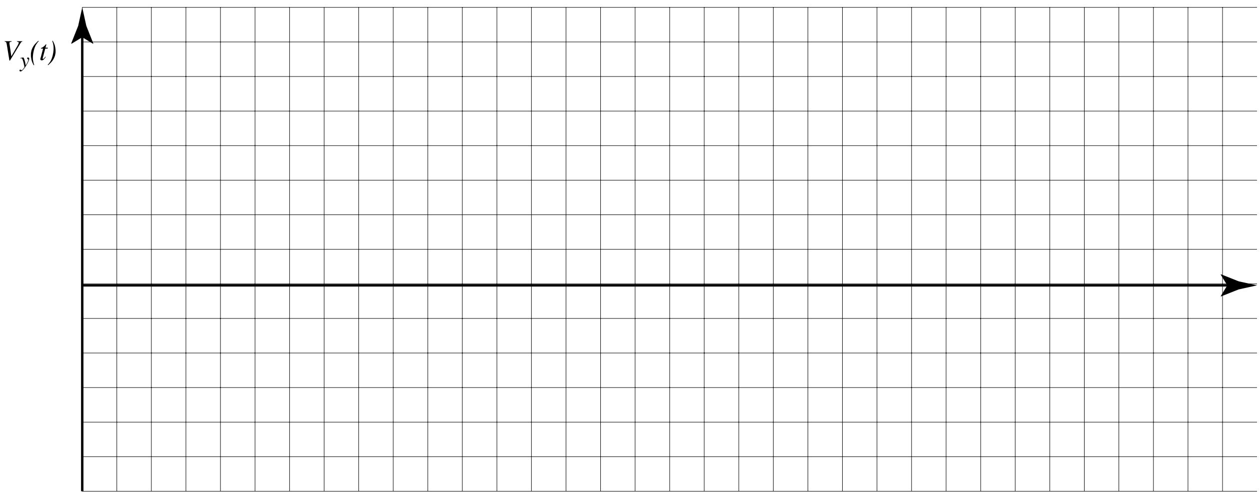


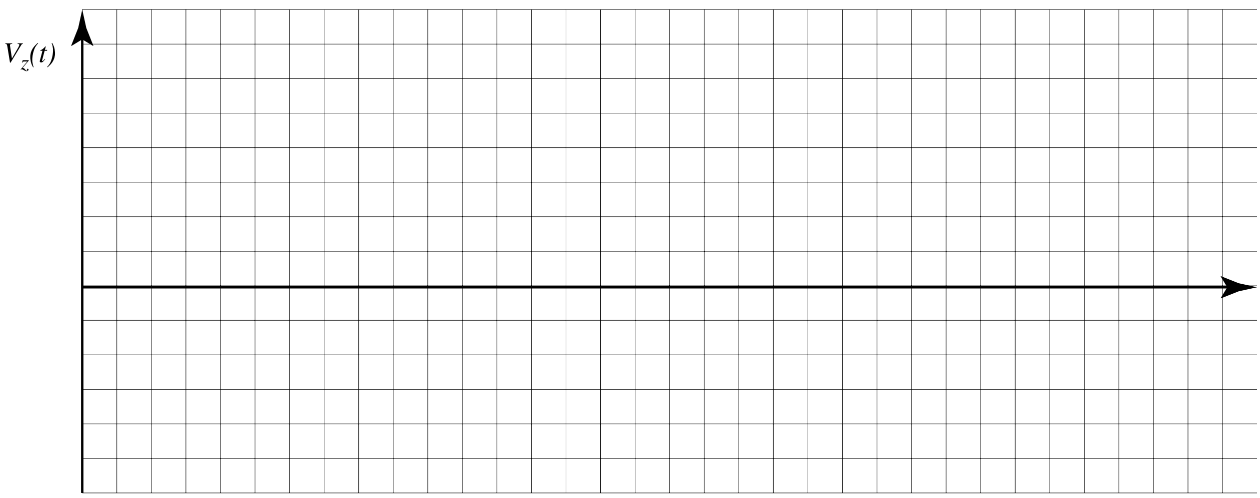
Sketch the three orthogonal scalar waveforms $V_x(t)$, $V_y(t)$, and $V_z(t)$ as defined in Figure 3.4 for one depolarization sequence. Label the time axis in terms of the radius of the spherical heart, a, and the velocity of propagation, v. [Note: try to be as quantitative as possible, but partial credit will be given for a qualitative answer.]

Figure 3.4:









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