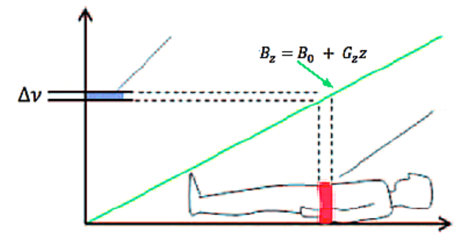
Physics 390 Practice Final

1. Consider the MRI set-up shown at right.



(A) You apply a slice selection gradient that relates frequency and position by the relationship:

$$\nu(z) = \bar{\gamma}B(z) = \bar{\gamma}(B_0 + G_z z) = \nu_0 + \bar{\gamma}G_z z$$

where the main magnetic field $B_0 = 1.5000\,T$ and $\bar{\gamma} = 42.5800\ \mathrm{MHz/T}$. Show that the resonance frequency at at z = 0 ($\nu_0 = \bar{\gamma}B_0$) is $63.8700\ \mathrm{Hz}$.

(B) Assume that a range of frequencies $63.9000 \pm 0.0002\ \mathrm{MHz}$ is used to excite protons in the patient. Also assume that the gradient strength $G_z = 10^{-2}\ \mathrm{T/m}$. What is the thickness of the excited slice?

(C) Determine the z location of the slice. (Hint: The z location is determined by the center frequency 63.9000.)

2. A table of brain component relaxation times and densities is shown at right. The MRI signal amplitude is given by the expression:

$$Signal\ Amplitude \propto \rho(1 - e^{-TR/T_1})e^{-TE/T_2}$$

Field strength (T)	Tissue	T_1 (ms)	T_2 (ms)	Proton density
1.5	White matter	510	67	0.61
	Gray matter	760	77	0.69
	Arterial blood	1441	290	0.72
	CSF	2650	280	1.0

(A) You conduct a two-dimensional spin-echo pulse sequence with a repetition time of 4000 ms and an echo time of 150 ms. Calculate the signal amplitude for CSF and white matter. Which component will be brighter?

(B) Is this a T_1- or T_2-weighted imaging protocol? Justify your answer!

3. You are collecting X-ray projection data from the object at right. The numbers in each box represent the extent of attenuation, and a zero means no attenuation.

0	0	5	0	0
0	3	6	4	1
0	5	10	2	0
0	1	8	0	0
0	0	2	0	0

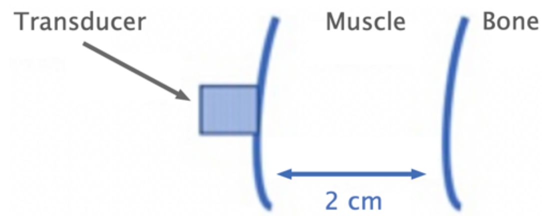
(A) In the matrix below, fill in the darkened empty column at the right of the object (labeled FP1) and darkened empty row at the bottom of the object (labeled FP2) with forward projection data.

						FP1
	0	0	5	0	0	
	0	3	6	4	1	
	0	5	10	2	0	
	0	1	8	0	0	
	0	0	2	0	0	
FP2						

(B) Use the two projections to generate a simple back projection image, which will be a blurred version of the object. Please recopy your forward projection data from (A) into the darkened right column and darkened bottom row in the matrix below. Please normalize your reconstruction.

						FP1
FP2						

4. Consider the ultrasound imaging experiment at right.



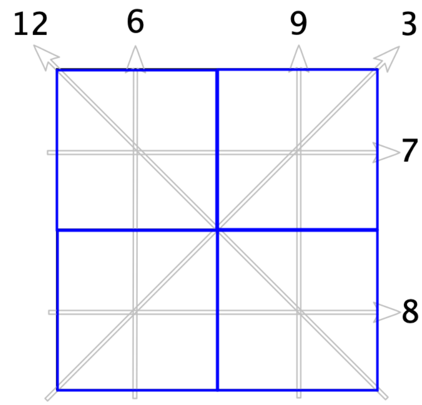
(A) A transducer sends out a 3-MHz ultrasound pulse, which then travels 2.0 cm in muscle before reflecting off of a muscle/bone interface. How long does it take for the echo to return to the transducer? Assume v_{sound} = 1500 m/s.

(B) Use the information at right to calculate the percent reflection at the muscle/bone interface.

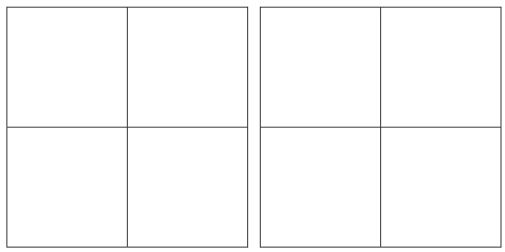
Tissue	Acoustic Impedance (kg/(m²s))	$R = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Air	0.0004×10^6	
Lung	0.18×10^6	
Fat	1.34×10^6	
Water	1.48×10^6	
Skin	1.6×10^6	
Kidney	1.63×10^6	
Blood	1.65×10^6	
Liver	1.65×10^6	
Muscle	1.71×10^6	
Bone	7.8×10^6	

(C) Assume that ultrasound attenuation in muscle follows the rule $L_{1/2}(cm) = 6/\nu$, where ν is in MHz, and that the intensity emitted by the transducer is 5 mW/cm². What is the intensity of the echo (in mW/cm²) when it returns to the transducer? *Hint: look carefully at Sample Problem 10.4, so you correctly account for both attenuation and reflection!*

5. Consider the 2×2 patient at right and the associated projection data. Reconstruct the object using the iterative approach, starting with an initial guess consisting of zeros.

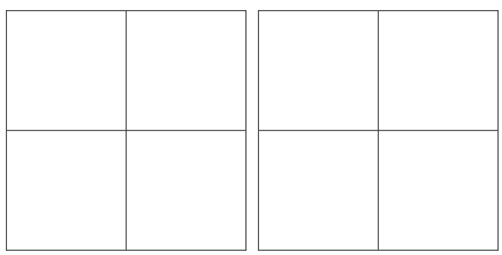


(A) Compute the first update from the two vertical line data 6 and 9.



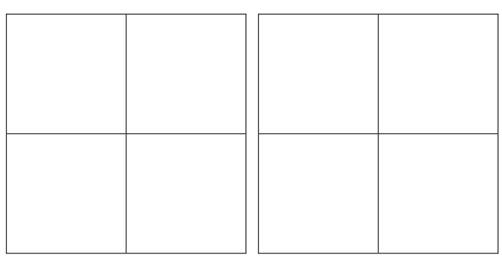
INITIAL GUESS   FIRST UPDATE

(B) Compute the second update using the two angled line data 12 and 3.



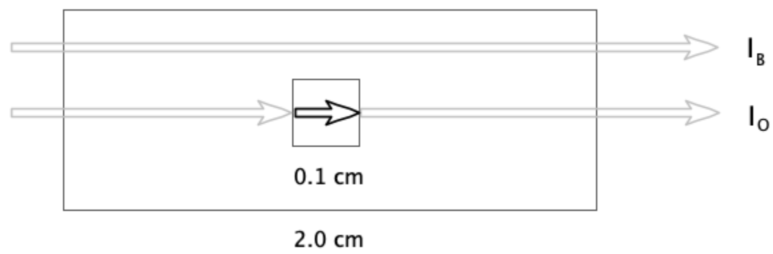
FIRST UPDATE   SECOND UPDATE

(C) Complete the final reconstruction by computing the third update using the two horizontal line data 7 and 8.



SECOND UPDATE   FINAL RESULT

6. Consider the object at right, which consists of a small feature with thickness 0.1 cm along the direction of X-ray propagation. The feature is embedded in a background region of thickness 2.0 cm. The linear attenuation coefficients of the object and background are 10.0 cm^{-1} and 1.0 cm^{-1}, respectively.



(A) Recall that attenuation of X-rays is exponential as specified by $I(x) = I_0 e^{-\mu x}$. Use this result to compute the intensity, I_B, that exits the line through just the background, as shown above.

(B) Similarly compute the intensity, I_O, that exits the line through the object and background, as shown above. Think carefully about how to implement attenuation through multiple regions!

(C) The local contrast is defined as $C_{local} = (I_B - I_O)/I_B$. Compute the local contrast.

(D) If object thickness were increased, what would happen to the local contrast (i.e., increase, decrease, remain unchanged)? Argue conceptually, not mathematically.

7. Sketch an $x/y/z$ coordinate system for an MRI experiment and then add:

(A) The equilibrium magnetization, M_0, and the main external magnetic field, B_0, along its conventional direction.

(B) The non-equilibrium magnetization, M_{xy}, after application of the standard perturbing pulse together with the MRI detector.

8. Fill in the blanks by choosing the technique that best suits your needs. Your technique options are:

Ultrasound, Conventional Radiography, Planar Nuclear Imaging

You want to:

(A) Image a fetus _________

(B) Visualize a tumor by monitoring tracer uptake _________

(C) Generate a mammogram _________

9. Fill in the blanks by choosing the technique that provides the best answer. Your technique options are:

CT, SPECT, PET, MRI

You want to:

(A) Generate a high-resolution image of the brain using non-ionizing radiation _________

(B) Image a tumor using 18-fluorine _________

(C) Generate a fast, overlap free anatomical image of a trauma patient _________

(D) Image bone using technetium-99m _________

10. Order the steps in a two-dimensional MRI pulse sequence:

A. Reconstruct the image	C. Apply a 90° excitation pulse and the slice selection gradient
B. Apply the phase-encoding gradient	D. Applying the frequency encoding gradient and acquire data

11. Match the techniques below to their “physical basis:

Ultrasound	A. Nuclear magnetism
PET	B. Coincidence detection of annihilation photons
CT	C. Echo ranging
MRI	D. Absorption via the photoelectric effect
	E. Emission of visible photons

12. Which of the following statements about ultrasound imaging are correct (circle all correct answers)?

(A) To image deep, use higher frequency

(B) To maximize resolution, use higher frequency

(C) Positive Doppler shifts imply that blood is moving towards the transducer

(D) Typical transducer frequencies range from ~2 – 10 kHz

(E) Many soft tissues reflect less than a percent of the incident ultrasound

13. Which of the following statements about contrast in X-ray-based imaging are correct (circle all correct answers)?

(A) Contrast improves as X-ray energy is increased

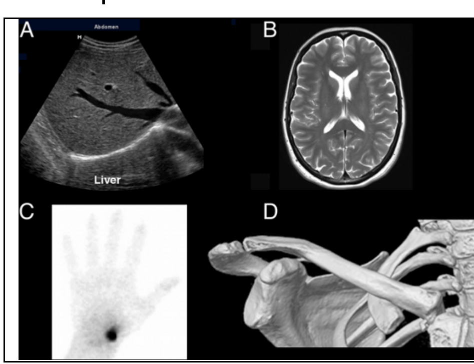
(B) Contrast improves with increasing object size

(C) The Compton effect has a positive effect on contrast

(D) Tissues with similar attenuation coefficients will generate good contrast

(E) Media containing iodine can enhance contrast

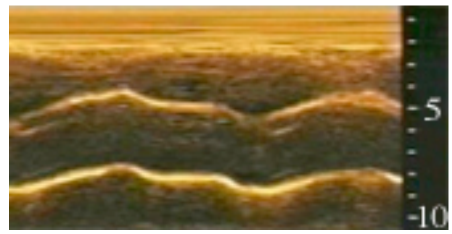
14. Below is a set of images. Each was generated by one of the main medical imaging techniques that we discussed:

	Which technique generated: Image A? _________________ Image B? _________________ Image C? _________________ Image D? _________________

Directions: Indicate if the following statements are true or false by writing T or F in the space provided.

1. _____ The penetration depth of ultrasonic waves falls off with increasing frequency.

2. _____ The image at right is probably an A mode ultrasound image.



3. _____ The Compton effect increases near an absorption edge.

4. _____ Contrast media used in X-ray imaging are based on elements with low atomic numbers.

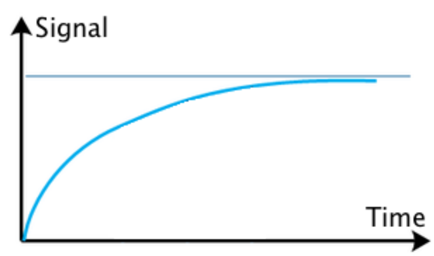
5. _____ Ultrasound is useful for imaging air-filled tissues, such as the lungs.

6. _____ X-rays cannot be used to produce quality images of soft tissue.

7. _____ Resolution in MRI is determined by the wavelength of radiofrequency radiation.

8. _____ Transverse magnetization typically relaxes more slowly than longitudinal magnetization.

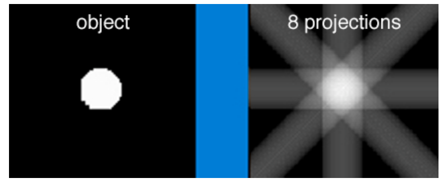
9. _____ The graph at right shows the temporal dependence of the transverse magnetization after application of a 90° pulse.



10. _____ To detect an ultrasound echo, a piezoelectric crystal converts an electrical signal into a mechanical signal.

11. _____ An ultrasound echo is detected after ~0.1 ms. The reflecting structure is ~7.5 cm deep. Assume v_{sound} = 1500 m/s.

12. _____ There are two images at right. One shows an object, and the other is the result of a back projection. Eight projections/views were required to produce the back projection.



13. _____ During slice selection, a z gradient is turned on and off and then a radiofrequency pulse is sent in that excites a slice resonating at the frequency of the pulse.

14. _____ Monoenergetic X-rays are incident on bone, which has an attenuation coefficient of ~0.5 cm^{-1}. The transmitted intensity is ~0.37×the incident intensity after the rays have penetrated 2.0 cm into bone.

15. _____ If a structure is not too thick, it is best to use lower energy X-rays if the goal is to achieve better contrast in an X-ray image.

16. _____ Start with the assumption, which is roughly correct, that protons resonate at 50 MHz in a 1 T field. This implies that protons resonate at 60 MHz in a 1.2 T field.