Applied Electromagnetics

Spring 2023

Homework 0

SOLUTION

Student Name

Student ID

February 29, 2060

Reading

Textbook

Elements of Electromagnetics, 7th Edition
Matthew Sadiku
Oxford University Press

Required Reading

Chapter 4, pp. 110-140.

Point Charges

Problem 1 – Single Charge

A single point charge of 7.2 nC resides at position $(0,0,0)$ within a silicon medium with relative permittivity $\varepsilon_{\mathrm{r}} = 3.5$. Calculate the electric field intensity $\vec{E}$ at position $(10\ \mathrm{mm}, -20\ \mathrm{mm}, 5.0\ \mathrm{mm})$.

Problem 2 – Two Charges

A first point charge of – 2.4 nC is at position $(1.0\ \mu\mathrm{m}, 2.0\ \mu\mathrm{m}, -3.0\ \mu\mathrm{m})$. A second point charge of 5.6 nC is at position $(-2.0\ \mu\mathrm{m}, 1.1\ \mu\mathrm{m}, 2.7\ \mu\mathrm{m})$. Both point charges reside in a ceramic medium with dielectric constant $\varepsilon_{\mathrm{r}} = 6.2$.

a) Calculate the electric field intensity $\vec{E}$ at position $(-0.5\ \mu\mathrm{m}, 0.5\ \mu\mathrm{m}, 0.5\ \mu\mathrm{m})$.

b) Calculate the force $\vec{F}$ on the second charge.

MATLAB

Problem 3 – Sine Function

Plot the function $1 + 2\sin(x)$ in the interval $-\pi/2 \leq x \leq \pi/2$. Be sure the plot is professional and publication ready. Include a graphics checklist at the end of the assignment.

Reading

I have completed the required reading for this assignment.

____
Student Name

Point Charges

Problem 1 – Single Charge

A single point charge of 7.2 nC resides at position $(0,0,0)$ within a silicon medium with relative permittivity $\varepsilon_{\mathrm{r}} = 3.5$. Calculate the electric field intensity $\vec{E}$ at position $(10\ \mathrm{mm}, -20\ \mathrm{mm}, 5.0\ \mathrm{mm})$.

Solution

The electric flux density $\vec{D}$ around a point charge is calculated independent of the relative permittivity of the medium according to

$$\vec{D} = \frac{Q\left(\vec{r} - \vec{r}_Q\right)}{4\pi\left|\vec{r} - \vec{r}_Q\right|^3} = \frac{(7.2\ \mathrm{nC})[(10\ \mathrm{mm}, -20\ \mathrm{mm}, 5.0\ \mathrm{mm}) - (0,0,0)]}{4\pi|(10\ \mathrm{mm}, -20\ \mathrm{mm}, 5.0\ \mathrm{mm}) - (0,0,0)|^3}$$

$$= \frac{(7.2\ \mathrm{nC})(10\ \mathrm{mm}, -20\ \mathrm{mm}, 5.0\ \mathrm{mm})}{4\pi\left[\sqrt{(10\ \mathrm{mm})^2 + (-20\ \mathrm{mm})^2 + (5.0\ \mathrm{mm})^2}\right]^3}$$

$$= (0.4763 \times 10^{-6}\ \mathrm{C/m^2}, -0.9526 \times 10^{-6}\ \mathrm{C/m^2}, 0.2382 \times 10^{-6}\ \mathrm{C/m^2})$$

The electric field intensity $\vec{E}$ is calculated from the electric flux density by taking into account the relative permittivity of the medium.

$$\vec{E} = \frac{\vec{D}}{\varepsilon_0 \varepsilon_{\mathrm{r}}} = \frac{(0.4763 \times 10^{-6}\ \mathrm{C/m^2}, -0.9526 \times 10^{-6}\ \mathrm{C/m^2}, 0.2382 \times 10^{-6}\ \mathrm{C/m^2})}{(8.854187812813 \times 10^{-12}\ \mathrm{F/m})(3.5)}$$

$$= (1.5370 \times 10^4\ \mathrm{V/m}, -3.0740 \times 10^4\ \mathrm{V/m}, 0.7685 \times 10^4\ \mathrm{V/m})$$

Expressing this in more convenient units gives

$$\boxed{\vec{E} = (15.4\ \mathrm{kV/m}, -30.7\ \mathrm{kV/m}, 7.68\ \mathrm{kV/m})}$$

Problem 2 – Two Charges

A first point charge of – 2.4 nC is at position $(1.0\ \mu\text{m}, 2.0\ \mu\text{m}, -3.0\ \mu\text{m})$. A second point charge of 5.6 nC is at position $(-2.0\ \mu\text{m}, 1.1\ \mu\text{m}, 2.7\ \mu\text{m})$. Both point charges reside in a ceramic medium with dielectric constant $\varepsilon_\text{r} = 6.2$.

a) Calculate the electric field intensity $\vec{E}$ at position $(-0.5\ \mu\text{m}, 0.5\ \mu\text{m}, 0.5\ \mu\text{m})$.

b) Calculate the force $\vec{F}$ on the second charge.

Solution

Part (a)

The electric flux density $\vec{D}_i$ is calculated separately for each point and then added.

$$\vec{D}_1 = \frac{Q_1(\vec{r} - \vec{r}_{Q1})}{4\pi|\vec{r} - \vec{r}_{Q1}|^3} = \frac{(-2.4\ \text{nC})[(-0.5\ \mu\text{m}, 0.5\ \mu\text{m}, 0.5\ \mu\text{m}) - (1.0\ \mu\text{m}, 2.0\ \mu\text{m}, -3.0\ \mu\text{m})]}{4\pi|(-0.5\ \mu\text{m}, 0.5\ \mu\text{m}, 0.5\ \mu\text{m}) - (1.0\ \mu\text{m}, 2.0\ \mu\text{m}, -3.0\ \mu\text{m})|^3}$$
$$= (4.1790\ \text{C/m}^2, 4.1790\ \text{C/m}^2, -9.7510\ \text{C/m}^2)$$

$$\vec{D}_2 = \frac{Q_2(\vec{r} - \vec{r}_{Q2})}{4\pi|\vec{r} - \vec{r}_{Q2}|^3} = \frac{(5.6\ \text{nC})[(-0.5\ \mu\text{m}, 0.5\ \mu\text{m}, 0.5\ \mu\text{m}) - (-2.0\ \mu\text{m}, 1.1\ \mu\text{m}, 2.7\ \mu\text{m})]}{4\pi|(-0.5\ \mu\text{m}, 0.5\ \mu\text{m}, 0.5\ \mu\text{m}) - (-2.0\ \mu\text{m}, 1.1\ \mu\text{m}, 2.7\ \mu\text{m})|^3}$$
$$= (32.8727\ \text{C/m}^2, -13.1491\ \text{C/m}^2, -48.2133\ \text{C/m}^2)$$

$$\begin{aligned}\vec{D}_\text{total} &= \vec{D}_1 + \vec{D}_2 \\ &= (4.1790\ \text{C/m}^2, 4.1790 \times 10^{-6}\ \text{C/m}^2, -9.7510\ \text{C/m}^2) \\ &\qquad + (32.8727\ \text{C/m}^2, -13.1491\ \text{C/m}^2, -48.2133\ \text{C/m}^2) \\ &= (37.0517\ \text{C/m}^2, -8.9701\ \text{C/m}^2, -57.9642\ \text{C/m}^2)\end{aligned}$$

The electric field intensity $\vec{E}$ is calculated from the electric flux density by taking into account the relative permittivity of the medium.

$$\vec{E}_\text{total} = \frac{\vec{D}_\text{total}}{\varepsilon_0 \varepsilon_\text{r}} = \frac{(37.0517\ \text{C/m}^2, -8.9701\ \text{C/m}^2, -57.9642\ \text{C/m}^2)}{(8.854187812813 \times 10^{-12}\ \text{F/m})(6.2)}$$
$$= (0.6749 \times 10^{12}\ \text{V/m}, -0.1634 \times 10^{12}\ \text{V/m}, -1.0559 \times 10^{12}\ \text{V/m})$$

Expressing this in more convenient units gives

$$\boxed{\vec{E} = (0.675\ \text{TV/m}, -0.163\ \text{TV/m}, -1.06\ \text{TV/m})}$$

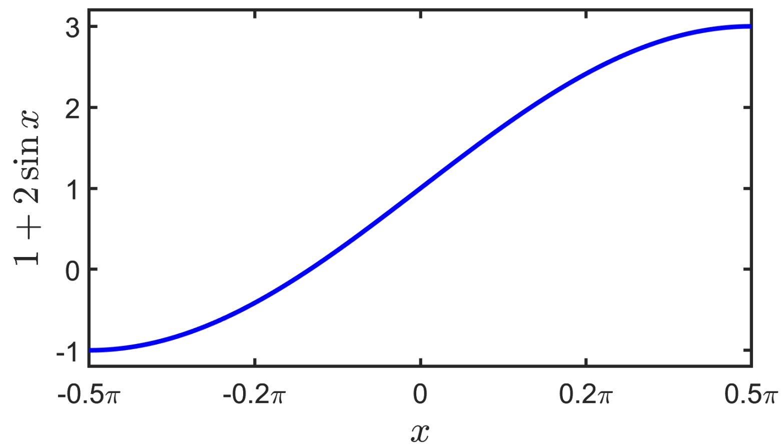
Electric fields are very intense at locations close to charges!

MATLAB

Problem 3 – Sine Function

Plot the function $1 + 2\sin(x)$ in the interval $-\pi/2 \leq x \leq \pi/2$. Be sure the plot is professional and publication ready. Include a graphics checklist at the end of the assignment.

Solution



Appendix A – MATLAB Codes

MATLAB Code for Problem 3

```
% HW0_Prob3.m
%
% Homework 0 -- Example
% Student Name
%
% Applied Electromagnetics
% Spring 2060

% INITIALIZE MATLAB
close all;
clc;
clear all;

% CALCULATE REQUIRED SINE FUCNTION
N = 1000;
x = linspace(-pi/2,+pi/2,N);
y = 1 + 2*sin(x);

% OPEN A FIGURE WINDOW
figure('Color','w');

% PLOT THE FUNCTION
plot(x,y,'-b','LineWidth',3);

% FORMAT PLOT
set(gca,'FontSize',18,'LineWidth',2);
xlabel('$x$','Interpreter','LaTex','FontSize',24);
ylabel('$1+2 \sin x$','Interpreter','LaTex','FontSize',24);
xlim([min(x) max(x)]);
ylim([-1.2 3.2]);

% SET X TICKS
T = pi*[-0.5:0.25:+0.5];
L = {};
for m = 1 : length(T)
    if T(m)==0
        L{m} = '0';
    else
        L{m} = [ num2str(T(m)/pi,'%3.1f') '\pi'];
    end
end
set(gca,'XTick',T,'XTickLabel',L);
```

Appendix B – Graphics Checklist

Graphics Checklist

Best Practices

- ☑ Graphic was made as compact as possible while still being easy to read and interpret.
- ☑ Graphic does not contain additional details that have nothing to do with what the diagram should convey.
- ☑ If the graphic is resized from its original size, ensure the criteria on this checklist are still met for the resized graphic.
- ☑ All colors are distinguishable and have adequate contrast when displayed in both color and grayscale.

Content

- ☑ All label items (i.e. text, lines, etc.) have sufficient contrast against the background to be easily read and distinguished. Consider highlights, outlines or color changes to help.
- ☑ The value of all numerical data is properly and clearly conveyed (color bars, labels, axes, etc.).
- ☑ All axes, dimensions, numerical data, etc., are labeled and given proper units.

Formatting

- ☑ All fonts are large enough to be read easily, but are not overbearing. Usually 10 to 18 point.
- ☑ All lines are wide enough to be easily visible, but are not overbearing. Usually 0.75 to 4 point.
- ☑ If possible, the xyz dimensions of objects and images are scaled equally so as not to distort the graphic. In MATLAB, this is done with `axis equal tight`.

Layout

- ☑ There are no large blank spaces that give the graphic an awkward feel or use space inefficiently.
- ☑ The graphic is well-organized, well-planned, and is not too busy.

Numbers & Equations

- ☑ All equations use correct fonts (e.g. Greek, Times, special symbols).
- ☑ Only variables are italicized (except uppercase Greek letters) and nothing else.
- ☑ All inline equations use horizontal formatting for fractions (i.e. $\pi/4$ instead of $\frac{\pi}{4}$).
- ☑ There exists a space between a number and its unit (i.e. 2.4 mm instead of 2.4mm).
- ☑ Units are consistent throughout the document (i.e. do not switch between inches and centimeters).

Quality

- ☑ All important entities in the graphic are easily distinguished, are identified, and are labeled.
- ☑ The graphic is of sufficient resolution not to be pixelated. Use at least 120 dpi (publishers prefer 600 dpi) and/or vector graphics.
- ☑ All colors are professional looking. Grayish and pastel colors tend to look best.

I have carefully reviewed my graphic and certify that all of the above criteria are met or exceeded.

[signature]
Signature

29 Feb 2060
Date