UNIVERSIDAD POLITECNICA DE VALENCIA

Second mid term exam FFI
November 25th 2019
Year 2019/20

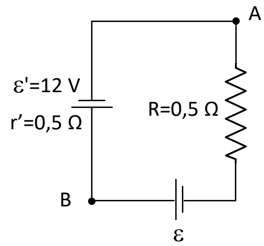
Applied Physics Dept.

1. (**2,5 points**) When the battery of a car becomes empty, it must be recharged by connecting the battery to a power supply. Therefore, **the battery is acting as a receptor**. The intensity needed to charge the battery is **I=4 A** constant during the charging process. The contraelectromotive force of the battery is **ε'=12 V** and its internal resistance **r'=0,5 Ω**. The resistance of the wires can be represented through a resistor of **0,5 Ω**, and the internal resistance of the power supply can be neglected as can be seen in the picture. Find:

a) (0,7) The **electromotive force** of the power supply.
b) (0,6) The **difference of potential** between points **A and B**.
c) (0,6) The **powers** put into play on power supply, battery and resistor (P_g, P_t, $P_{r'}$, P_c and P_R) . State a **balance of power**.
d) (0,3) Compute the **efficiency** of **battery.**
e) (0,3) If the charging process takes **10 h**, compute the total energy stored in the battery. The main parameter of a battery is usually given in **A·h**. Which quantity can be measured in **A·h**?

1. (**2,5 puntos**) Cuando la batería de un coche se descarga, debe recargarse conectándola a una fuente de alimentación. Entonces, **la batería actúa como un receptor**. La corriente necesaria para recargar la batería es de **I=4 A** constante durante toda la carga. La fuerza contraelectromotriz de la batería es **ε'=12 V** y su resistencia interna **r'=0,5 Ω**. La resistencia de los cables puede representarse mediante una resistencia de **0,5 Ω**, y la resistencia interna de la fuente de alimentación puede despreciarse, como puede verse en el dibujo. Calcula:

a) (0,7) La **fuerza electromotriz** de la fuente de alimentación.
b) (0,6) La **diferencia de potencial** entre los puntos **A y B** del circuito.
c) (0,6) Las **potencias** puestas en juego en la fuente de alimentación, batería y resistencia (P_g, P_t, $P_{r'}$, P_c and P_R). Haz un **balance de potencias**.
d) (0,3) Calcula el **rendimiento** de la **batería**.
e) (0,3) Si el proceso de carga dura **10 h**, calcula la energía total almacenada en la batería. El principal parámetro de una batería se da, normalmente, en **A·h**. ¿Qué magnitud se mide en **A·h**?



Solution:

a) In order the battery acts as a receptor, the intensity must flow in clockwise direction. Then:

$$I=\frac{\sum(\varepsilon+\varepsilon')}{\sum R}=4=\frac{\varepsilon-12}{1}\Rightarrow\varepsilon=4+12=16\,V$$

b) If we go from A to B along the path with the resistor and the battery: $V_{AB}=I\sum R-(\varepsilon+\varepsilon')=4(0,5)-16=-14\,V$

c) $P_g=\varepsilon I=16\cdot 4=64\,w$ $\quad P_t=\varepsilon' I=12\cdot 4=48\,w$ $\quad P_{r'}=I^2 r'=16\cdot 0,5=8\,w$ $\quad P_c=P_t+P_{r'}=48+8=56\,w$

$P_R=I^2R=16\cdot 0,5=8\,w$ Obviously, the generated power must be equal to the consumed power:

$P_g=P_c+P_R\Rightarrow 64=56+8$

d) $\eta'=\frac{P_t}{P_c}=\frac{48}{56}\approx 0,86\Rightarrow\eta'\text{ is near }86\%$

e) 10 h = 3600·10=36000 s. Therefore $W=P_t\cdot t=48\cdot 36000=1728\,kJ$

A is a unit of intensity of current (charge/time). The product of an intensity by a time is a charge. Therefore, the A·h is a unit of electric charge.

2. (**3 points**) Given the **circuit** on picture, compute:

a) (1) Intensity of current flowing along each branch with the shown directions, $\mathbf{I_1}$, $\mathbf{I_2}$ and $\mathbf{I_3}$. Say if devices ε_1 and ε_2 are **acting as generators or receptors**.

b) **Potential** of point **B**.

c) (1) **Tehevenin's equivalent generator** between points **B** and **D**, clearly showing its polarity.

d) (0,5) A **new branch** (that shown on right) is connected between points **B** and **D**. Is the 6 V generator of the new branch, **generating or consuming energy**? Compute its **generated or consumed power**.

e) (0,5) **Tehevenin's equivalent generator** between points **A** and **C**, clearly showing its polarity.

2. (**3 puntos**) Dado el **circuito** de la figura, calcula:

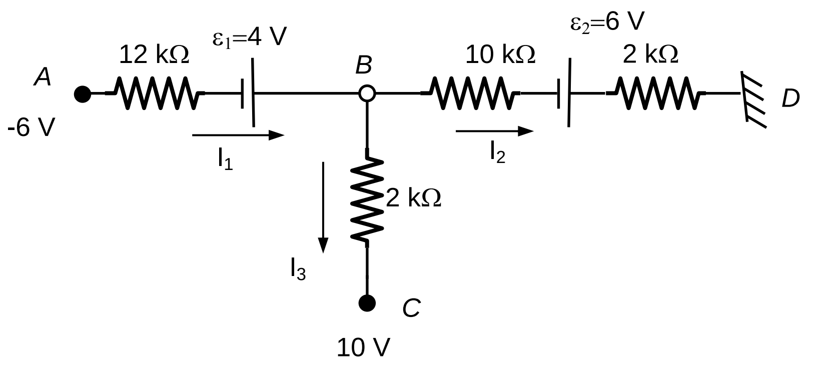
a) (1) La intensidad de corriente en cada rama con los sentidos mostrados, $\mathbf{I_1}$, $\mathbf{I_2}$ y $\mathbf{I_3}$. Indica si los elementos ε_1 y ε_2 **actúan como generadores o receptores**.

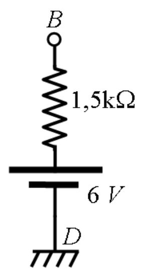
b) **Potencial** del punto **B**.

c) (1) El **generador equivalente de Thevenin** entre los puntos **B y D**, indicando claramente su polaridad.

d) (0,5) Al circuito se le **añade** una **nueva rama** (la mostrada a la derecha) **entr**e los puntos **B** y **D**. Indica si el elemento de 6 V de la nueva rama, **genera o consume energía** y calcula su **valor**.

e) (0,5) El **generador equivalente de Thevenin** entre los puntos **A y C**, indicando claramente su polaridad.





Solution:

This is a network with 2 junctions and two loops, and so we'll need one equation for junctions and two equations for loops:

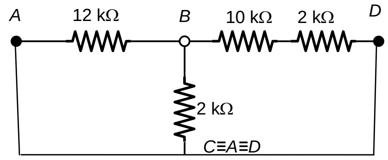
a) $$\left.\begin{aligned} I_1 &= I_2 + I_3 \\ V_{AD} = -6 &= 12I_1 - 4 + 12I_2 - 6 \\ V_{CD} = 10 &= -2I_3 + 12I_2 - 6 \end{aligned}\right\} \Rightarrow I_1 = -\frac{17}{24}mA \quad I_2 = \frac{25}{24}mA \quad I_3 = -\frac{7}{4}mA$$

According the computed intensities, ε_1 is acting as a receptor and ε_2 is acting as a generator.

b) $V_{BC} = V_B - 10 = 2I_3 = 2\cdot(-\frac{7}{4}) = -\frac{7}{2} \Rightarrow V_B = 10 - \frac{7}{2} = \frac{13}{2}\ V$

c) $\varepsilon_T = V_{BD} = V_B - V_D = \frac{13}{2} - 0 = \frac{13}{2} V$

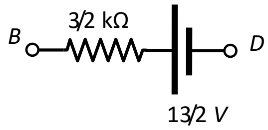
Passive circuit after removing all the generators is



and its equivalent resistance between B and D:

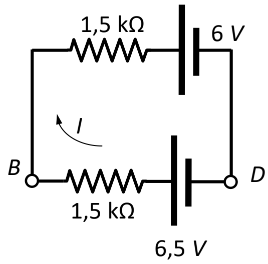
$$\frac{1}{R_{eqBD}} = \frac{1}{10} + \frac{1}{2} + \frac{1}{10+2} \Rightarrow R_{eqBD} = \frac{3}{2} k\Omega$$

So, Thevenin's equivalent generator between B and C is:



d) If we connect the new branch between points B and D, the resulting circuit is that on picture. The intensity flowing in clockwise direction is:

$$I = \frac{6,5-6}{3} = \frac{1}{6} mA$$

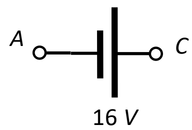


The 6 V battery of the new branch is consuming energy. The consumed power is

$$P_c = \varepsilon' I = 6\cdot\frac{1}{6} = 1\,mW$$

d) $\varepsilon_T = V_{AC} = -6 + 10 = -16\,V$ And $R_{eqAC} = 0$

Therefore, the Thevenin's equivalent generator between A and C is



3. (2 points) The rectangular **solenoid** on picture, with cross **section 6x4=24 cm^2** is flowed by a current ***I=4 A*** in the shown direction. It makes a **60º a**ngle with the positive direction of the Y axis, and tghe number of **turns is 500**. Compute:

a) (0,8) The **magnetic moment** $\vec{\mu}$ of the solenoid.

b) (0,6) The **torque** $\vec{\tau}$ of the forces acting on it when a **uniform magnetic field** $\vec{B} = 2\vec{i} - 3\vec{j}\ T$ is applied.

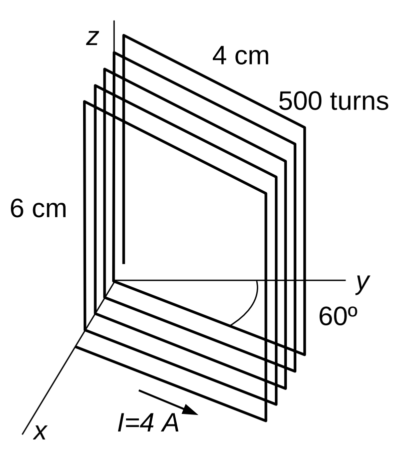
c) (0,6) The **force** acting on the side of solenoid lying on the Z axis.

3. (2 puntos) La **bobina** rectangular de la figura, de **sección 6x4=24 cm^2** está recorrida por una corriente ***I=4 A*** en el sentido indicado. Forma un **ángulo de 60º** con la dirección positiva del eje Y, y tiene **500 espiras**. Calcula:

a) (0,8) El **momento magnético** de la bobina, $\vec{m}$.

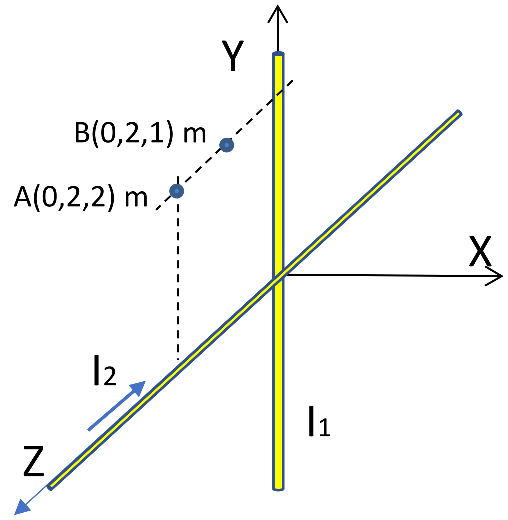
b) (0,6) El **momento** $\vec{M}$ de las fuerzas que actúan sobre ella si se le aplica un **campo magnético uniforme** $\vec{B} = 2\vec{i} - 3\vec{j}\ T$.

c) (0,6) La **fuerza** que actúa sobre el lado de la bobina coincidente con el eje Z.



Solution: a) $\vec{\mu} = NI\vec{S} = 500 \cdot 4 \cdot 24 \cdot 10^{-4}(\cos 60º\,\vec{i} - sen 60º\,\vec{j}) = 2,4\vec{i} - 4,2\vec{j}\ Am^2$ b) $\vec{\tau} = \vec{\mu} \times \vec{B} = (2,4\vec{i} - 4,2\vec{j}) \times (2\vec{i} - 3\vec{j}) = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 2,4 & -4,2 & 0 \\ 2 & -3 & 0 \end{vmatrix} = (-7,2 + 8,4)\vec{k} = 1,2\vec{k}\ Nm$ c) $\vec{F}_1 = NI\vec{L} \times \vec{B} = 500 \cdot 4 \cdot (-6 \cdot 10^{-2}\vec{k}) \times (2\vec{i} - 3\vec{j}) = -360\vec{i} - 240\vec{j}\ N$

4. (**2,5 points**) Two **infinite** straight carrying current **conductors** are placed on **plane YZ**, lying on **axes Y and Z** respectively. They carry equal currents **$I=I_1=I_2$**, being the direction of I_2 that shown on picture. The **modulus** of magnetic field at point **A(0,2,2) m** is **$B_A=10^{-5}$ T**. Find: a) (0,6) The **direction of current I_1** (to up or to down) and the **direction of magnetic field** at point **A** ($+\vec{i}$ or $-\vec{i}$). **Justify** the answer. b) (0,6) The magnitude of **I.** c) (0,7) The **magnetic field vector** at point **B(0,2,1) m.** d) (0,6) Give the **coordinates** of a point where the **magnetic field was null**.	**4.** (**2,5 puntos**) Dos **conductores** rectilíneos e **indefinidos** están colocados en el **plano YZ**, sobre los **ejes Y y Z**, respectivamente. Llevan corrientes iguales **$I=I_1=I_2$**, siendo la dirección de I_2, la mostrada en la figura. El **módulo** del campo magnético en el punto **A(0,2,2) m** es **$B_A=10^{-5}$ T**. Halla: a) (0,6) La **dirección de la corriente I_1** (hacia arriba o hacia abajo), y la **dirección del campo magnético** en **A** ($+\vec{i}$ ó $-\vec{i}$). **Justifica** la respuesta. b) (0,6) El valor de **I**. c) (0,7) El **vector campo magnético** en el punto **B(0,2,1) m.** d) (0,6) Da las **coordenadas** de un punto donde se **anule el campo magnético.**



Solution:

On every case, the magnetic field is the summatory of magnetic field produced by each conductor:

a) If I_1 was flowing to downwards, then the magnetic field at point A would be null. Therefore, I_1 has to flow upwards. Then, the magnetic field at point A must go in the positive direction of X axis, $+\vec{i}$.

b) $\vec{B}_A = \vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I}{2\pi \cdot 2}\vec{i} + \frac{\mu_0 I}{2\pi \cdot 2}\vec{i} = \frac{\mu_0 I}{2\pi}\vec{i} = 2I \cdot 10^{-7}\vec{i}$

According the statement $\quad 2I \cdot 10^{-7} = 10^{-5} \Rightarrow I = 50\ A$

c) $\vec{B}_B = \vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I}{2\pi \cdot 1}\vec{i} + \frac{\mu_0 I}{2\pi \cdot 2}\vec{i} = \frac{3\mu_0 I}{4\pi}\vec{i} = 3I \cdot 10^{-7}\vec{i} = 150 \cdot 10^{-7}\vec{i} = 15 \cdot 10^{-6}\vec{i}\ T$

d) The magnetic field can only be null at points over the plane YZ, on second and forth quadrants. Moreover, as the intensities on both conductors are equal, these points must be placed over the angle bisector of such quadrants. For example, the point (0,-1,1) would be a point where the magnetic field would be null.

FORM

Direct current $V_A - V_B = I\sum R - \sum \varepsilon$ $\quad I = \frac{\sum \varepsilon}{\sum R}$ $\quad P = V \cdot I$ $\quad \varepsilon = \frac{dW}{dq}$ $\quad P_R = I^2 \cdot R$ $\quad P_g = \varepsilon \cdot I$ $\quad P_t = \varepsilon' \cdot I$ $\quad P_g - P_r = P_s$ $\quad P_t + P_{r'} = P_c$

$\eta_g = \frac{P_s}{P_g}$ $\quad \eta_r = \frac{P_t}{P_c}$

Magnetic Forces $\vec{F} = q(\vec{v} \times \vec{B})$ $\quad d\vec{F} = Id\vec{l} \times \vec{B}$ $\quad \vec{\mu} = N \cdot I \cdot \vec{S}$ $\quad \vec{\tau} = \vec{\mu} \times \vec{B}$ $\quad V_H = \frac{I \cdot B \cdot d}{n \cdot e \cdot S}$

Sources of magnetic field $d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{d\vec{\ell} \times \vec{r}}{r^3}$ $\quad \mu_0 = 4\pi 10^{-7}$ (I.S.units) $\quad B = \frac{\mu_0 I}{2\pi x}$

$B = \frac{\mu_0 I}{2R}$ $\quad \oint_L \vec{B} \cdot d\vec{l} = \mu_0 \sum I$ $\quad B = \frac{\mu_0 N I}{l}$