THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

131/2 **PHYSICS 2**

(For Both School and Private Candidates)

Time: 2:30 Hours **ANSWERS** **Year: 1999**

Instructions

1. This paper consists of section A, B and C with total of nine questions.
2. Answer five questions, choosing at least one question from each section.
3. Each question carries twenty marks.

1. (a) Define "Young's Modulus" of a material and give its SI units

Young's modulus (Y) is a measure of the stiffness of a material. It is defined as the ratio of tensile stress to tensile strain.

Y = stress / strain

where
stress = force per unit area (N/m^2)
strain = relative change in length (dimensionless)

SI unit: Pascal (Pa) or N/m^2

(b) With the aid of a sketch graph, explain what happens when a steel wire is stretched gradually by an increasing load until it breaks

When a steel wire is stretched, the load-extension graph follows these phases:

- Proportional limit: The extension is directly proportional to the applied force (Hooke's law).
- Elastic limit: The wire returns to its original shape when the force is removed.
- Yield point: The wire undergoes plastic deformation and does not return to its original shape.
- Necking and breaking: The wire thins in certain regions before eventually snapping.

(c) A force F is applied to a long steel wire of length L and cross-sectional area A

(i) Show that if the wire is considered to be a spring, the force constant k is given by

$k = \Delta Y / L$

where Y is Young's Modulus of the wire

Using Hooke's law:

$F = k \Delta L$

From Young's modulus:

$Y = (F L) / (A \Delta L)$
$F = (Y A \Delta L) / L$

Comparing with Hooke's law:

$k = (Y A) / L$

(ii) Show that the energy stored in the wire is $U = \frac{1}{2} F \Delta L$, where ΔL is the extension of the wire

The work done in stretching the wire is stored as potential energy:

$U = \int F\, dL$ from 0 to ΔL

Substituting $F = (Y A \Delta L) / L$:

$U = \int (Y A L / L)\, dL$
$U = \frac{1}{2} (Y A \Delta L^2) / L$

Since $F = (Y A \Delta L) / L$,

$U = \frac{1}{2} F \Delta L$

(d) The period T of vibrations of a tuning fork may be expected to depend on the density D, Young's modulus Y of the material of which it is made, and the length a of its prongs. Using dimensional analysis deduce an expression for T in terms of D, Y, and a

Assume T is proportional to powers of D, Y, and a:
$T \propto D^x Y^y a^z$

Writing dimensions:

$[D] = kg/m^3$, $[Y] = N/m^2 = kg/m \cdot s^2$, $[a] = m$

$[T] = [D]^x [Y]^y [a]^z$

$s = (kg/m^3)^x (kg/m \cdot s^2)^y (m)^z$

Equating dimensions:

$M^0 L^0 T^1 = (M \times L^{-3})^x (M L^{-1} T^{-2})^y (L)^z$

Solving for powers of M, L, and T:
M: $0 = x + y$
L: $0 = -3x - y + z$
T: $1 = -2y$

Solving $y = -1/2$, $x = 1/2$, and $z = 1$,

$T = a \sqrt{(D / Y)}$

2. (a) Explain the meaning of the following terms

(i) Gravitational Potential of the Earth

Gravitational potential is the work done per unit mass to move a mass from infinity to a point in the Earth's gravitational field.

$V = - GM / r$

(ii) Gravitational Field Strength of the Earth

Gravitational field strength is the force per unit mass experienced by a small test mass at a point in the gravitational field.

$g = GM / r^2$

How are the above quantities in (i) and (ii) related?

$g = - dV / dr$

(b) Show that the total energy of a satellite in a circular orbit equals half its potential energy

Total energy:

$E = KE + PE$

$KE = ½ mv^2$, $PE = - GMm / r$

For circular motion, $GMm / r = mv^2$

Substituting in total energy equation:

$E = ½ GMm / r - GMm / r$
$E = - ½ GMm / r$

Total energy is half the potential energy.

(c) Calculate the height above the Earth's surface for a satellite in a parking orbit

Using the formula for orbital radius:

$r = (GM / v^2)$

where
$G = 6.674 \times 10^{-11}\ N\cdot m^2/kg^2$
$M = 5.972 \times 10^{24}\ kg$
$v = 7.9 \times 10^3\ m/s$

$r = (6.674 \times 10^{-11} \times 5.972 \times 10^{24}) / (7.9 \times 10^3)^2$

$r \approx 4.2 \times 10^7\ m$

Height above surface = r - Earth's radius

$h = 4.2 \times 10^7 - 6.37 \times 10^6$
$h \approx 3.56 \times 10^7\ m$

(d) What would be the length of a day if the rate of rotation of the Earth were such that the acceleration of gravity g = 0 at the equator?

At g = 0, centrifugal force equals gravitational force:

$m\omega^2R = GMm / R^2$

$\omega^2 = GM / R^3$

$T = 2\pi / \omega$

Solving for T:
$T \approx 1.41$ hours

3. (a) What do you understand by the term "moments of inertia" of a rigid body?

Moment of inertia is the measure of a body's resistance to angular acceleration about an axis. It is given by:

$I = \int r^2\, dm$

(b) (i) State the perpendicular axes theorem of moments of inertia for a body in the form of a lamina

The perpendicular axes theorem states that the moment of inertia about an axis perpendicular to the plane of a lamina is equal to the sum of the moments of inertia about two perpendicular axes in the plane.

$I_z = I_x + I_y$

(ii) Calculate the moments of inertia of a thin circular disc of radius 50 cm and mass 2 kg about an axis along a diameter of the disc

Using formula for a disc about a diameter:

$I = \frac{1}{2} MR^2$

$M = 2$ kg, $R = 0.5$ m

$I = \frac{1}{2} \times 2 \times (0.5)^2$
$I = 0.25\ kg \cdot m^2$

(c) A wheel mounted on an axle that is not frictionless is initially at rest. A constant external torque of 50 Nm is applied to the wheel for 20 s. At the end of the 20 s, the wheel has an angular velocity of 600 rev/min. The external torque is then removed, and the wheel comes to rest after 120 s more.

(i) Determine the moment of inertia of the wheel

Using torque equation:

$\tau = I\alpha$

$\alpha = \Delta\omega / \Delta t$

$\omega = 600$ rev/min $= 62.83$ rad/s

$\alpha = (62.83 - 0) / 20$
$\alpha = 3.14\ rad/s^2$

$I = \tau / \alpha$
$I = 50 / 3.14$
$I \approx 15.9\ kg \cdot m^2$

(ii) Calculate the frictional torque which is assumed to be constant

Using α after torque is removed:

$\alpha = (0 - 62.83) / 120$
$\alpha = -0.523\ rad/s^2$

Frictional torque:

$\tau_f = I\alpha$

$\tau_f = 15.9 \times (-0.523)$
$\tau_f \approx -8.3$ Nm

4. (a) State the main assumptions of the "kinetic theory" of gases
   - Gas molecules are in constant random motion.
   - The size of gas molecules is negligible compared to the container.
   - Collisions between molecules are elastic.
   - The average kinetic energy is proportional to temperature.

(b) Derive an expression for the pressure exerted by an ideal gas on the walls of its container
Using Newton's second law and kinetic energy relations,
$P = (1/3) (N/V) m v^2$
where N = number of molecules, m = molecular mass, v^2 = mean square speed.

4. (c) How does the average translational kinetic energy of a molecule of an ideal gas change if:

(i) The pressure is doubled while the volume is kept constant

From the kinetic theory equation:

$KE_{avg} = (3/2) kT$

Since pressure (P) and temperature (T) are directly proportional at constant volume ($P \propto T$), doubling the pressure doubles the temperature, which in turn doubles the average kinetic energy.

(ii) The volume is doubled while the pressure is kept constant

Using the ideal gas equation:

$PV = nRT$

At constant pressure, if volume (V) is doubled, temperature (T) must also be doubled. Since KE_{avg} is proportional to T, the average kinetic energy is also doubled.

(d) Calculate the value of the root mean-square speed of molecules of helium at 0°C

The root mean-square speed is given by:

$v_{rms} = \sqrt{3RT / M}$

where
R = 8.314 J/mol·K
T = 273 K (0°C)

M = molar mass of helium = 4.002×10^{-3} kg/mol

$v_{rms} = \sqrt{(3 \times 8.314 \times 273 / 4.002 \times 10^{-3})}$

First, calculate the numerator:

$3 \times 8.314 \times 273 = 6802.5$

Now, divide by M:

$6802.5 / (4.002 \times 10^{-3}) = 1.7 \times 10^{6}$

Taking the square root:

$v_{rms} = \sqrt{(1.7 \times 10^{6})}$
$v_{rms} \approx 1302$ m/s
The root mean-square speed of helium molecules at 0°C is approximately 1302 m/s.

5. (a) (i) What is "capacitance"?

Capacitance (C) is the ability of a conductor to store charge per unit potential difference. It is given by:

$C = Q / V$

where
Q = charge stored
V = voltage applied

SI unit: Farad (F)

(ii) List three factors that govern the capacitance of a parallel plate capacitor

- The area (A) of the plates – larger area increases capacitance.
- The separation (d) between the plates – smaller separation increases capacitance.
- The permittivity (ε) of the dielectric material between the plates – higher permittivity increases capacitance.

(b) Show that the energy per unit volume stored in a parallel plate capacitor is given by:

$U = \frac{1}{2} \varepsilon E^2$

Using energy stored in a capacitor:

$U = \frac{1}{2} C V^2$

For a parallel plate capacitor:

$C = \varepsilon A / d$
$V = Ed$

Substituting:

$U = \frac{1}{2} (\varepsilon A / d) (E d)^2$
$U = \frac{1}{2} \varepsilon A E^2 d$

Dividing by volume (A d):

$U / (A d) = \frac{1}{2} \varepsilon E^2$

Thus, energy density is:

$U = \frac{1}{2} \varepsilon E^2$

(c) Given that the distance of separation between the parallel plates of a capacitor is 5 mm, and the plates have an area of 5 m². A potential difference of 10 kV is applied across the capacitor which is parallel in vacuum.

Compute:

(i) The capacitance

$C = \varepsilon_0 A / d$

where
$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m
$A = 5$ m²
$d = 5$ mm $= 5 \times 10^{-3}$ m

$C = (8.85 \times 10^{-12} \times 5) / (5 \times 10^{-3})$
$C = (4.425 \times 10^{-11}) / (5 \times 10^{-3})$
$C = 8.85 \times 10^{-9}$ F

Capacitance = 8.85 nF

(ii) The electric intensity in the space between the plates

$E = V / d$

$V = 10 \text{ kV} = 10^4 \text{ V}$

$E = 10^4 / (5 \times 10^{-3})$
$E = 2 \times 10^6 \text{ V/m}$

Electric field intensity = 2×10^6 V/m

(iii) The change in the stored energy if the separation of the plates is increased from 5 mm to 5.5 mm

Energy stored is given by:

$U = \frac{1}{2} C V^2$

When d = 5 mm,

$C_1 = 8.85 \times 10^{-9} \text{ F}$
$U_1 = \frac{1}{2} (8.85 \times 10^{-9}) \times (10^4)^2$
$U_1 = 4.425 \times 10^{-4} \text{ J}$

When d = 5.5 mm,

$C_2 = \varepsilon_0 A / d_2$
$C_2 = (8.85 \times 10^{-12} \times 5) / (5.5 \times 10^{-3})$
$C_2 = 8.05 \times 10^{-9} \text{ F}$

$U_2 = \frac{1}{2} (8.05 \times 10^{-9}) \times (10^4)^2$
$U_2 = 4.025 \times 10^{-4} \text{ J}$

Change in energy:

$\Delta U = U_2 - U_1$
$\Delta U = 4.025 \times 10^{-4} - 4.425 \times 10^{-4}$
$\Delta U = -4 \times 10^{-5} \text{ J}$

The decrease in stored energy is 4×10^{-5} J.

6. (a) With the help of illustrative diagrams explain the action of a choke in a circuit

A choke is an inductor used in circuits to limit the rate of change of current. It opposes sudden current variations by inducing a counter-electromotive force (emf) according to Faraday's Law. It is commonly used in power supplies to filter high-frequency AC components while allowing DC to pass.

(b) When an impedance consisting of an inductance L and a resistance R in series is connected across a 12V, 50Hz power supply, a current of 0.050A flows, which differs in phase from that of the applied potential difference by 60°.

(i) Find the value of R and L
Impedance in an RL circuit is given by:
$Z = \sqrt{R^2 + X_L^2}$

where
X_L = inductive reactance = $2\pi fL$
Also, phase angle is given by:

$\tan(\theta) = X_L / R$
Given:
$V = 12V, I = 0.050A, f = 50Hz, \theta = 60°$
First, find impedance:

$Z = V / I$
$Z = 12 / 0.050$
$Z = 240\ \Omega$

Using $\tan(60°) = \sqrt{3}$:

$\sqrt{3} = X_L / R$

Now, using $Z^2 = R^2 + X_L^2$:

$240^2 = R^2 + (\sqrt{3} R)^2$
$57600 = 4R^2$
$R = \sqrt{(57600 / 4)}$
$R = 120\ \Omega$

Now, solving for L:
$X_L = \sqrt{3} \times 120$
$X_L = 207.8\ \Omega$

$L = X_L / (2\pi f)$

$L = 207.8 / (2\pi \times 50)$
$L \approx 0.66$ H

(ii) Find the capacitance of the capacitor which, when connected in series in the above circuit, has the effect of bringing the current into phase with the applied voltage

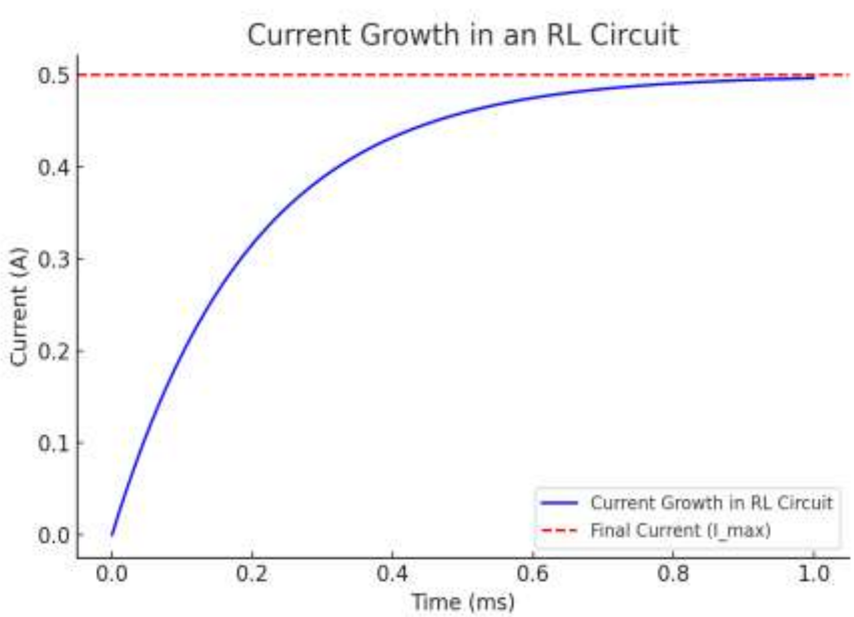
For resonance,
$X_L = X_C$
$X_C = 1 / (2\pi fC)$

Solving for C:
$C = 1 / (2\pi \times 50 \times 207.8)$
$C \approx 15.3\ \mu F$

(c) An inductance of 4 mH is connected in series with a resistance of 20Ω together with a battery
(i) Determine how the current will vary with time in this circuit
The current in an RL circuit follows:

$I(t) = I_{max} (1 - e^{(-t/\tau)})$
where
$\tau = L / R = 4 \times 10^{-3} / 20$
$\tau = 0.2$ ms

(ii) Sketch the current of (i) above against time



The graph will show an exponential rise, reaching 63% of its final value at $t = \tau$.

(iii) Calculate the inductive time constant

$\tau = L / R$
$\tau = 4 \times 10^{-3} / 20$
$\tau = 0.2$ ms

7. (a) State the laws of electromagnetic induction and describe briefly experiments (one in each case) which can be used to demonstrate them

- Faraday's First Law: A changing magnetic field induces an emf in a conductor.
  - Demonstrated by moving a magnet in and out of a coil, generating current in a galvanometer.

- Faraday's Second Law: The induced emf is proportional to the rate of change of magnetic flux.
  - Demonstrated using a rotating coil in a magnetic field.

- Lenz's Law: The induced current opposes the cause producing it.
  - Demonstrated using a copper ring repelling a falling magnet.

(b) A flat coil of 100 turns and mean radius 5.0 cm is lying on a horizontal surface and is turned over in 0.20 sec. against the vertical component of the Earth's magnetic field. Calculate the average e.m.f. induced

Using Faraday's Law:

$e = - N \Delta\Phi / \Delta t$

where
$N = 100$
$B = 5 \times 10^{-5}$ T (typical Earth's magnetic field)
$A = \pi r^2 = \pi(0.05)^2 = 7.85 \times 10^{-3}$ m²
$\Delta t = 0.20$ s

Initial flux:

$\Phi_1 = B \times A = 5 \times 10^{-5} \times 7.85 \times 10^{-3}$
$\Phi_1 = 3.93 \times 10^{-7}$ Wb

Final flux $\Phi_2 = -\Phi_1$ (since it flips 180°)

$\Delta\Phi = \Phi_2 - \Phi_1 = -3.93 \times 10^{-7} - 3.93 \times 10^{-7}$
$\Delta\Phi = -7.86 \times 10^{-7}$ Wb

Now,

$e = -(100 \times -7.86 \times 10^{-7}) / 0.20$
$e = 3.93 \times 10^{-4}$ V

Induced emf ≈ 0.393 mV

(d) With the help of clear diagrams, explain briefly how you would convert a sensitive galvanometer into:

(i) An ammeter

A low-resistance shunt resistor is connected in parallel to allow high current to pass while protecting the galvanometer.

(ii) A voltmeter

A high resistance is connected in series to allow voltage measurement with minimal current draw.

8. (a) State Bohr's postulates of the atomic model

- Electrons revolve in stable orbits without emitting radiation.
- Angular momentum is quantized as $L = n\hbar$.
- Electrons absorb/emission energy during transitions between energy levels.

(b) Show that for an electron in a hydrogen atom, the possible radii of an electron orbit are given by:

$r_n = a_0 n^2$

Using Coulomb force = centripetal force:

$k e^2 / r^2 = m v^2 / r$

Using quantized angular momentum:

$m v r = n\hbar$

Solving for r,

$r_n = (\hbar^2 / ke^2m) n^2$

Let a_0 = Bohr radius = 5.29×10^{-11} m,

$r_n = a_0 n^2$

(c) (i) Show that the possible energy levels (in Joules) for the hydrogen atom are given by:

$E_n = - (me^4 / 8h^2\varepsilon_0^2) \times (1 / n^2)$

Using energy relations,
$E = KE + PE$
$E = ½ ke^2 / r - ke^2 / r$

Solving for E,
$E_n = - (me^4 / 8h^2\varepsilon_0^2) \times (1 / n^2)$

(ii) What does the negative sign signify in the formula for E_n in (i) above?

The negative sign indicates that the electron is bound to the nucleus, and energy must be supplied to free it.

9. (a) Define the term "binding energy" of a nuclide

Binding energy is the energy required to separate a nucleus into its individual protons and neutrons.

(b) Distinguish between:

(i) β^- decay and β^+ decay

β^- decay: A neutron decays into a proton, emitting an electron and an antineutrino.
β^+ decay: A proton decays into a neutron, emitting a positron and a neutrino.

(ii) Nuclear fission and nuclear fusion

Fission: A heavy nucleus splits into smaller nuclei, releasing energy.
Fusion: Light nuclei combine to form a heavier nucleus, releasing energy.

(iii) Activity and half-life of a radioactive material

Activity: The rate of radioactive decay per unit time.
Half-life: The time taken for half the radioactive material to decay.

(iv) Taking the half-life of Radium-226 to be 1600 years, what fraction of a given sample remains after 4800 years?

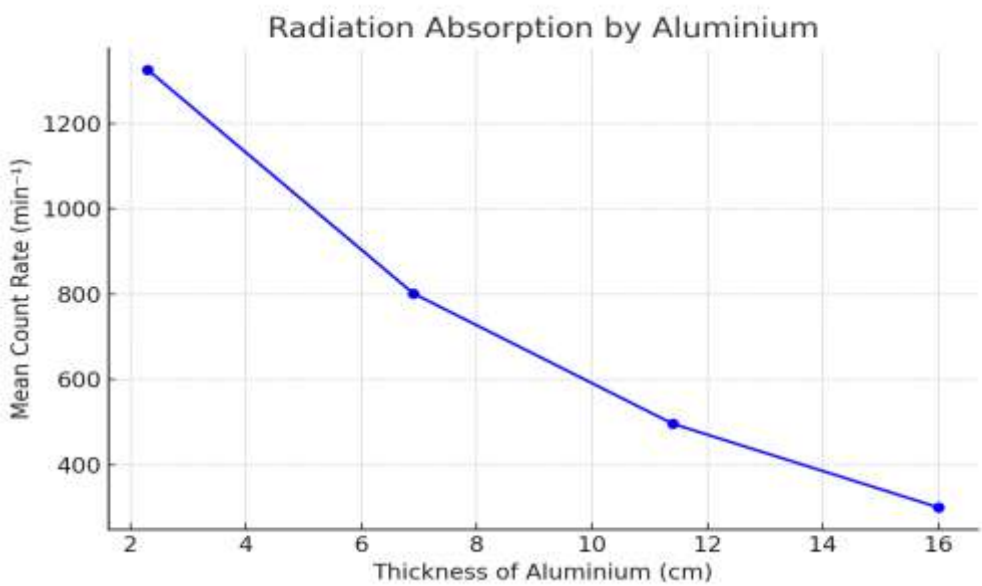
Using the half-life formula:

$N / N_0 = (1/2)^{(t/T)}$

where
t = 4800 years
T = 1600 years

$N / N_0 = (1/2)^{(4800/1600)}$
$N / N_0 = (1/2)^3$
$N / N_0 = 1/8$

The remaining fraction is 1/8.

(c) 

10. (a) Briefly describe the major factors that you would consider when designing a voltage amplifier

- Gain – The amplifier should provide sufficient voltage gain to amplify weak signals without excessive distortion.
- Bandwidth – The frequency range over which the amplifier operates effectively should match the application's needs.
- Input and Output Impedance – The input impedance should be high to avoid loading effects, and the output impedance should be low to drive the load effectively.
- Stability – The amplifier should not oscillate or be affected by temperature variations and component tolerances.

- Power Efficiency – The circuit should consume minimal power while delivering adequate performance.
- Noise Performance – The amplifier should have low noise levels to maintain signal integrity.
- Distortion – Harmonic and intermodulation distortion should be minimized to ensure signal fidelity.

(b) (i) Explain the term "thermal run away" as regards a transistor amplifier

Thermal runaway occurs when an increase in temperature causes an increase in collector current, which further increases power dissipation and temperature, leading to an uncontrollable rise in current. This can damage the transistor if not controlled.

(ii) With the help of clear diagrams, explain how you would overcome thermal run away in a voltage amplifier

Thermal runaway can be prevented by:
- Using Negative Feedback – A feedback resistor stabilizes the biasing and limits excessive current.
- Heat Sinks – Dissipate excess heat to maintain transistor temperature.
- Using Biasing Stabilization Circuits – Voltage divider biasing reduces the effect of temperature changes on current.
- Thermistors – Temperature-dependent resistors help in compensating for variations in temperature.

(c) Figure (1) shows a junction transistor voltage amplifier circuit. If $R_1 = 100k\Omega$, $R_2 = 1k\Omega$, $V_{cc} = 6.0V$, $V_{BE} = 0.6V$, and $h_{FE} = 60$, calculate:

(i) The voltage across R_1

The voltage across R_1 is given by:

$V_{R_1} = V_{cc} - V_{BE}$

$V_{R_1} = 6.0 - 0.6$
$V_{R_1} = 5.4V$

(ii) The value of I_B

Using Ohm’s law:

$I_B = V_{R_1} / R_1$

$I_B = 5.4V / 100k\Omega$
$I_B = 5.4 \times 10^{-5}$ A
$I_B = 54\ \mu A$

(iii) The value of I_C

Using the current gain formula:

$I_C = h_{FE} \times I_B$

$I_C = 60 \times 54 \times 10^{-6}$
$I_C = 3.24$ mA

(iv) The voltage across R_2

$V_{R_2} = I_C \times R_2$

$V_{R_2} = 3.24 \times 10^{-3} \times 1 \times 10^{3}$
$V_{R_2} = 3.24V$

(v) The collector-emitter voltage

$V_{CE} = Vcc - V_{R_2}$

$V_{CE} = 6.0 - 3.24$
$V_{CE} = 2.76V$