41. Electric Current through Gases

Short Answer

1. Question

Why is conduction easier in gases if the pressure is low? Will the conduction continue to improve if the pressure is made as low as nearly zero?

Answer

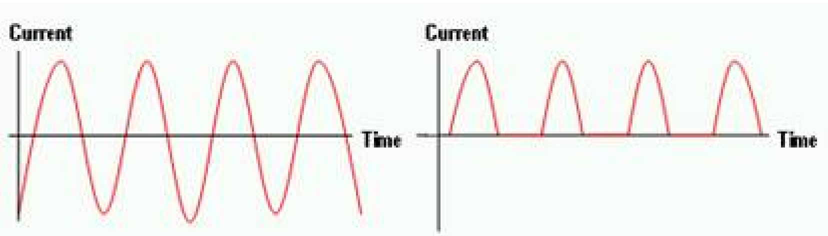
Conduction happens when an electron with enough kinetic energy collides with the electron of gas atoms. This process is called as ionization of gas atoms. This phenomenon is reported at low pressure, as at high pressure the mean free path of electron decrease which results in a collision of electron much before they get enough kinetic energy for ionization. Whereas at low pressure due to an increase in their mean free path they are able to gain enough kinetic energy for ionization process so conduction is easier. If the pressure is made too low, there won't be enough atoms to ionize and hence conductivity will decrease.

2. Question

An AC source is connected to a diode and a resistor in series. Is the current through the resistor AC or DC?

Answer

When an AC source is connected to a diode half rectification of the source will happen and we will get a pulsating DC output.



The resistor in series would be getting a pulsating DC output. The given circuit in question is analogous to half rectification of AC source by diode, in that circuit we use resistor for measuring the load of DC.

3. Question

How will the thermionic current vary if the filament current is increased?

Answer

Thermionic current will increase if the filament current is increased as due to increase in temperature in filament. It is due to internal resistance through which the temperature of filament increases. This increase in temperature will give enough kinetic energy to electrons to leave the surface of filament and it will lead to increase in number of thermions number leaving per unit surface area of filament and hence thermionic current will increase.

4. Question

Would you prefer a material having a high melting point or a low melting point to be used as a cathode in a diode?

Answer

We know that electrons which are responsible for thermionic current will leave the surface at high temperature. Therefore, cathode material should be able to handle high temperature which will only be possible if the material has a high melting point.

5. Question

Would you prefer a material having a high work function or a low work function to be used as a cathode in a diode?

Answer

Work function's magnitude accounts for how much energy we need to provide for the emission of electron from the surface. Therefore, we would prefer material having low work function as less energy will be required for emission.

6. Question

An isolated metal sphere is heated to a high temperature. Will it become positively charged due to thermionic emission?

Answer

When an isolated metal sphere is heated to high temperature it will give enough kinetic energy to electrons and hence will the surface. This will decrease the number of electrons on the surface of metal sphere. And due this reason the sphere will become positively charged.

7. Question

A diode valve is connected to a battery and a load resistance. The filament is heated so that a constant current is obtained in the circuit. As the cathode continuously emits electrons, does it get more and more positively charged?

Answer

The important thing to note in this question is that diode's cathode is connected to battery's negative terminal. When filament is heated it will continuously emit electrons from it but battery's negative terminal will also provide electrons which makes the diode electrically neutral in nature

8. Question

Why does thermionic emission not take place in non-conductors?

Answer

No, non-conductors will not take part in thermionic emission due to a high work function. Also, Non-conductors do not have free electrons present on its surface hence no electrons are able to emit from it. Whereas in conductors, due to the presence of free-electrons on its surface it accounts for thermionic emission.

9. Question

The cathode of a diode valve is replaced by another cathode of double the surface area. Keeping the voltage and temperature conditions the same, will the plate current decrease, increase or remain the same?

Answer

The plate current will increase. We know the more the surface area of cathode more number of electrons will be present on it and hence probability of electrons leaving the surface also increases which in turn increase the plate's current.

10. Question

Why is the linear portion of the triode characteristic chosen to operate the triode as an amplifier?

Answer

We know that in the linear portion of the triode characteristic graph, it has the least amount of distortion as comparted to other region of graph. This gives an advantage that voltage across the resistor will vary accordingly to input signal and amplification can be achieved easily without risking the life of vacuum tube.

Objective I

1. Question

Cathode rays constitute a stream of

A. electrons

B. protons

C. positive ions

D. negative ions

Answer

Cathode is responsible for thermionic emission and thermionic emission is due to electrons which leave its surface. Therefore, rays should constitute a stream of electrons.

Ions are present due to gases but they do not account for rays from cathode surface as only electrons are the one leaving the surface.

2. Question

Cathode rays are passing through a discharge tube, in tube, there is

A. an electric field but no magnetic field.

B. a magnetic field but no electric field

C. an electric as well as a magnetic field

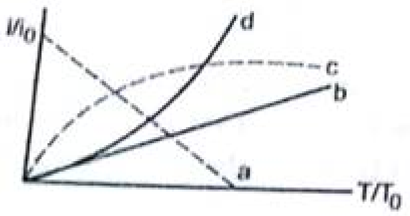
D. neither an electric nor a magnetic field

Answer

We know that cathode rays constitute a stream of electrons which are responsible for thermionic emission. Therefore, field will be created hence option D should be ruled out. We know it is due to charge magnetic field is created. We also know that magnetic field and electric field complement each other. Magnetic and electric field concepts are relative to each other, that it depends on which frame of reference you are taking about hence both fields are created inside tube

3. Question

Let i0 be the thermionic current from a metal surface when the absolute temperature of the surface is T0. The temperature is slowly increased and the thermionic current is measured as a function of temperature. Which of the following plots may represent the variation in (i/i0) against (T/T0)?



Answer

We know that current in thermionic emission varies to square of Temperature. of cathode with exponential term

$J \propto T^2 * e^{-1/T}$

The best suited curve from the figures which satisfy the equation is the parabolic one.

4. Question

When the diode shows saturated current, dynamic plate resistance is

A. zero

B. infinity

C. indeterminate

D. different for different diodes

Answer

We know the dynamic plate resistance is given by

$$R = \Delta V_p / \Delta I_p$$

Now when diode is at saturated current region the change in ΔI_P will be very small or it will be near to zero, therefore dynamic resistance will at infinity.

It can't be indeterminate as although it will saturate current but still changes in decimal places will be still be visible and hence ΔI_P will not be equal to zero.

5. Question

The anode of a thermionic diode is connected to the negative terminal of a battery and the cathode to its positive terminal.

A. No appreciable current will pass through the diode.

B. A large current will pass through the diode from the anode to the cathode.

C. A large current will pass through the diode from the cathode to the anode.

D. The diode will be damaged.

Answer

When cathode is connected to positive terminal and anode to negative terminal electrons will not able to leave the surface of cathode and hence no thermionic emission will be accounted. This will result in no current passing through diode.

6. Question

A diode, a resistor and a 50 Hz AC source are connected in series. The number of current pulses per second through the resistor is

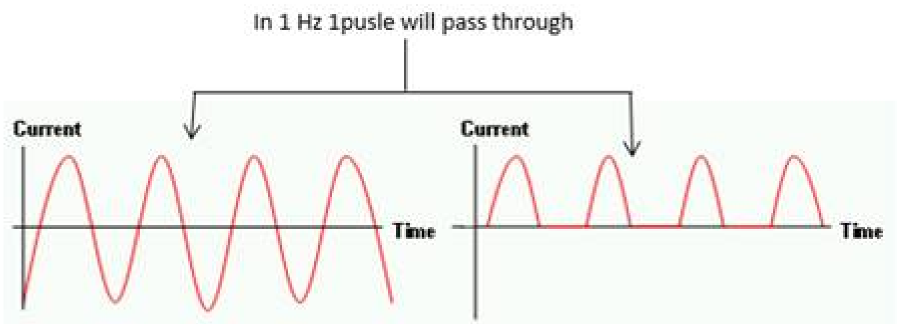
A. 25

B. 50

C. 100

D. 200

Answer



We can see from figure that in one second 1 pulse will pass through when 1Hztherefore total of 50 pulses will pass through in one second

7. Question

A triode is operated in the linear region of its characteristics. If the plate voltage is slightly increased, the dynamic plate resistance will

A. increase

B. decrease

C. remain almost the same

D. become zero

Answer

We know the formula for dynamic plate resistance is

$R = \Delta V_p/\Delta I_p$

When triode is operating in linear region, and plate voltage is slightly changed it will lead to change in current of plate and hence both of these effect will cancel each other and no change in resistance will be observed.

8. Question

The plate current in a triode valve is maximum when the potential of the grid is

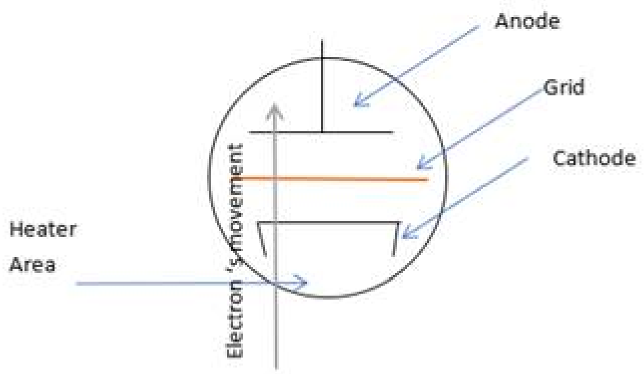
A. positive

B. zero

C. negative

D. non-positive

Answer



We know electrons get attracted to positive potential. When potential of the grid is made positive it makes easier for us to push electrons from cathode to anode which accounts for increase in current. Hence plate current in a triode valve is maximum when the potential of the grid is made positive

9. Question

The amplification factor of a triode operating in the linear region depends strongly on

A. the temperature of the cathode

B. the plate potential

C. the grid potential

D. the separations of the grid from the cathode and the anode.

Answer

When the triode operating in the linear region, it indirectly

implies that the grid voltage, plate voltage and plate current is

specified and hence plays no contribution to the amplification factor in this question

Now if the grid is too near the cathode it will partially or completely lie in space charge region which comprises of electrons from the cathode. And hence it will pick electrons from cathode more rapidly which will increase the plate current and hence amplification factor will get affected. As amplification factors depend on the plate's current.

And when the grid is far away from cathode, it will able to pick as many electrons compared to when it was near to cathode and hence amplification factor will get affected

Objective II

1. Question

Electric conduction takes place in a discharge tube due to the movement of

A. positive ions

B. negative ions

C. electrons

D. protons

Answer

Cathode ray which comprises of electrons is mainly responsible for electric conduction. But ions are also present in gases which play a role in conduction by getting ionized by colliding with electrons which are present in cathode rays. This process is called ionization which also contributes to electric conduction. Therefore, both positive and negative ions with electrons are responsible for conduction

2. Question

Which of the following are true for cathode ray?

A. It travels along straight lines.

B. It emits X-ray when strikes a metal

C. It is an electromagnetic wave

D. It is not deflected by magnetic field.

Answer

Cathode rays are wave but due to their massless property they are not able to travel at speed which is equal to light hence they are not categorized under Electromagnetic wave.

Cathode consists of Electrons and they will travel from cathode to anode by the shortest route which is obliviously a straight line until any other forces are applied across the tube. In presence of magnetic field, they will deviate from their usual path.

When cathode accelerated to the anode they produce X-rays, which is in accordance to Maxwell's principle that accelerating charge emit radiation when it strikes the surface of metal.

3. Question

Because of the space charge in a diode valve,

A. the plate current decreases

B. the plate voltage increases

C. the rate of emission of thermions increases

D. the saturation current increases.

Answer

Space charge is three dimensional concept. It is a cloud of electrons which are distributed evenly over the 3D space rather than being at one place. As we know cathode emits electrons and this electron take some finite amount of time to travel and due to this a region near cathode is created which create repulsion for electrons which are coming cathode. This phenomenon is called space charge effect. This decrease the plate’s current.

This Space charge has no effect on the rate of emission of thermions, as rate depend on how much energy we are providing to it. Also it is not related to saturation current or plate’s voltage.

4. Question

The saturation current in a triode valve can be changed by changing

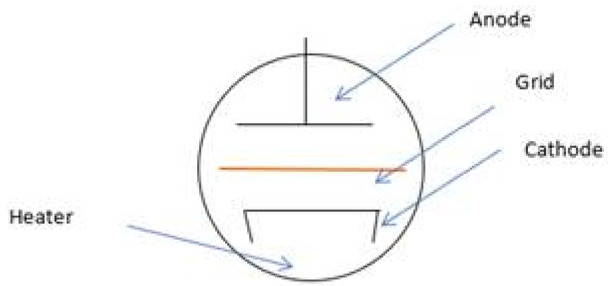
A. the grid voltage

B. the plate voltage

C. the separation between the grid and the cathode

D. the temperature of the cathode

Answer



Grid Voltage when made negative, it will not allow the electrons from cathode to pass through, as electrons will start repealing from it hence this will decrease the electric conductivity. Whereas when grid voltage is made positive it will start attracting electrons and make it easier for electrons to leave the surface of cathode. Therefore, through grid voltage we are indirectly controlling the plate's current. Also in triode valve we know that the maximum current is the saturation current, hence by controlling the grid voltage we are in a way controlling the saturation current. Whereas separation won't make any difference as it is the voltage which is actually plays an important role in controlling the plate's current. Changing the separation will only effect the amplification.

No matter what is the temperature of cathode is, at the end it depends whether grid allows the electrons to pass through to it or not. Therefore, it is the grid voltage which effects the saturation current.

5. Question

Mark the correct options.

A. A diode valve can be used as a rectifier

B. A triode valve can be used as a rectifier

C. A diode valve can be used an amplifier

D. A triode valve can be used as an amplifier

Answer

We know triode has a property through which output can be controlled and it is due to this property triode is used as amplifier. This property of manipulating output is not present in diode therefore it can't be used as amplifier.

Also, it is well known fact that diode and triode allow only in single direction flow of current through it and hence they act as rectifier for AC input and convert it to pulsating DC.

6. Question

The plate current in a diode is zero. It is possible that

A. the plate voltage is zero

B. the plate voltage is slightly negative

C. the plate voltage is slightly positive

D. the temperature of the filament is low

Answer

A. the plate voltage is zero

B. the plate voltage is slightly negative

C. the plate voltage is slightly positive

D. the temperature of the filament is low

When the temperature of the filament is low, then there is a possibility that not enough kinetic energy is being produced and due to these electrons may not able to leave the surface of the cathode and hence zero current in a diode. When plate voltage is zero it means indirectly that current is zero as we know both are in direct relation to each other. And when the plate's voltage is negative with respect to cathode no electrons will leave the surface and hence zero current. Now when the voltage is slightly positive, it may be that it is not greater than forward voltage and hence electrons are not able to accelerate towards the anode. As we know around cathode a cloud of electrons formed and when voltage is not enough for electrons, they will not able to reach the anode.

7. Question

The plate current in a triode valve is zero. The temperature of the filament is high. It is possible that

A. $V_g > 0, V_p > 0$

B. $V_g > 0, V_p < 0$

C. $V_g < 0, V_p > 0$

D. $V_g < 0, V_p < 0$

Answer

B. $V_g > 0, V_p < 0$

C. $V_g < 0, V_p > 0$

D. $V_g < 0, V_p < 0$

Here Vg means voltage grid and Vp means positive plate's voltage. Now it is already given in question that temperature of the filament is high therefore electrons have enough kinetic energy to leave the surface of cathode.

But still even if grid voltage is negative, electrons will not able to reach the surface of anode and hence no current will be visible Also if positive plate's voltage is negative, then also electrons won't be able to reach the anode's surface. Therefore, current will be zero even if one of the above conditions are met.

Exercises

1. Question

A discharge tube contains helium at a low pressure. A large potential difference is applied across the tube. Consider a helium atom that has just been ionized due to the detachment of an atomic electron. Find the ratio of the distance travelled by the free electron to that by the positive ion in a short time dt after the ionization.

Answer

Let the distance travelled by free electron and positive ion be S_E and S_H respectively. Also, mass of the electron and positive helium ion be m_e and m_h where,

$m_e=9.1\times10^{-31}$kg

$m_h=4\times$mass of proton

$=4\times1.6\times10^{-27}$kg

We know,

$$S = ut + \frac{at^2}{2}$$

where s is the distance travelled, u is the initial velocity, t is the time and a is the magnitude of acceleration

Here, initial velocity of electron and helium ion is zero

$$\therefore S = \frac{at^2}{2}$$

Now, magnitude of force experienced by electron,

$$F = qE$$

$$m_e a = qE$$

$$a = \frac{qE}{m_e}$$

where F is the magnitude of force, E is the electric field strength and q is the magnitude of charge of the particle.

$\therefore$ Distance travelled by free electron for dt duration is $S_e = \frac{qE}{2m_e} \times (dt)^2$

Magnitude of force experienced by positive helium ion,

$$F = qE$$

$$m_h a = qE$$

$$a = \frac{qE}{m_h}$$

$\therefore$ Distance travelled by positive helium ion for dt duration is$S_h = \frac{qE}{2m_h} \times dt^2$

The required ratio is

$$\frac{S_e}{S_h} = \frac{\frac{qE}{2m_e} \times dt^2}{\frac{qE}{2m_h} \times dt^2}$$

$$\frac{S_e}{S_h} = \frac{m_h}{m_e} = \frac{4 \times 1.6 \times 10^{-27}}{9.1 \times 10^{-31}}$$

$$\frac{S_e}{S_h} = \frac{m_h}{m_e} = 7340.6$$

2. Question

A molecule of a gas, filled in a discharge tube, gets ionized when an electron is detached from it. An electric field of 5.0 kV m^{-1} exists in the vicinity of the event.

(a) Find the distance travelled by the free electron in 1 μs assuming no collision.

(b) If the mean free path of the electron is 1.0 mm, estimate the time of transit of the free electron between successive collisions

Answer

a) Given electric field E= 5 kV m^{-1} = 5×10^3 V m^{-1}

Time t=1 μs = 1×10^{-6} s.

Let m be the mass of electron and q be the charge of electron where m=9.1×10^{-31} kg

q =1.6×10^{-19} C

We know,

$$F = qE$$

$$ma = qE$$

$$a = \frac{qE}{m}$$

where F is the force, E is the electric field strength and q is the magnitude of charge.

Also, distance travelled by an electron is

$S = \frac{at^2}{2}$ (as initial velocity is 0)

$$S = \frac{qE}{2m} \times t^2$$

$$= \frac{1.6 \times 10^{-19} \times 5 \times 10^3 \times 10^{-12}}{2 \times 9.1 \times 10^{-31}}$$

$$= 439.5 \text{ m}$$

b) Here mean free path S travelled by electron is given as S=1mm

$=10^{-3}$ m

We know,

$$a = \frac{qE}{m} = \frac{1.6 \times 10^{-19} \times 5 \times 10^3}{9.1 \times 10^{-31}} = 0.87 \times 10^{15}$$

Also,

$$S = \frac{at^2}{2}$$

$$\Rightarrow t^2 = \frac{2S}{a}$$

$$\Rightarrow t^2 = \frac{2 \times 10^{-3}}{0.87 \times 10^{15}} = 2.29 \times 10^{-18} \text{ s}$$

$$\Rightarrow t = 1.51 \times 10^{-9} \text{ s} = 1.5 \text{ ns.}$$

3. Question

The mean free path of electrons in the gas in a discharge tube is inversely proportional to the pressure inside it. The Crookes dark space occupies half the length of the discharge tube when the pressure is 0.02 mm of mercury. Estimate the pressure at which the dark space will fill the whole tube.

Answer

Let the mean free path be L and pressure be P

Given, $L \propto \frac{1}{P}$ where L = half of the tube length and P = 0.02 mm of Hg

∴ When P becomes half, L doubles, i.e. the whole tube is filled with Crook's dark space.

Hence the required pressure $= \frac{0.02}{2} = 0.01$ m of Hg.

4. Question

Two discharge tubes have identical material structure and the same gas is filled in them. The length of one tube is 10 cm and that of the other tube is 20 cm. Sparking starts in both the tubes when the potential difference between the cathode and the anode is 100 V. If the pressure in the shorter tube is 1.0 mm of mercury, what is the pressure in the longer tube?

Answer

Let d1 and p1 be the length and pressure of short tube. Also d2 and p2 be the length and pressure of long tube.i.e. p1=1.0 mm d1=10 cm, d2=20 cm

According to Paschen's law,

$V = f\,(pd)$, i.e. the sparking potential of a gas in a discharge tube is the function of the product of pressure of the gas and separation between the electrodes.

$$\therefore\ V = p1d1 = p2d2$$

$$\Rightarrow p2 = \frac{p1d1}{d2} = \frac{1 \times 10}{20} = 0.5 \text{ mm}$$

5. Question

Calculate n(T)/n (1000 K) for tungsten emitter at T = 300 K, 2000 K and 3000 K where n(T) represents the number of thermions emitted per second by the surface at temperature T. Work function of tungsten is 4.52 eV.

Answer

According to Richardson-Dushman Equation thermionic current i is

$$i = ne = AST^2\, e^{-\phi/kT}$$

where, n is the thermions emitted, S is the surface area, T is the absolute temperature, k is the Boltzmann constant, A is the constant depend on nature of metal and ϕ is the work function.

Case 1

T=300 K

Now, $$\frac{n(T)}{n(1000)} = \frac{AS300^2\ e^{\frac{-4.52\times1.6\times10^{-19}}{1.38\times10^{-23}\times300}}}{AS1000^2\ e^{\frac{-4.52\times1.6\times10^{-19}}{1.38\times10^{-23}\times1000}}} = 7.057\times10^{-55}$$

Case 2

T=2000 K

Now, $$\frac{n(T)}{n(1000)} = \frac{AS2000^2\ e^{\frac{-4.52\times1.6\times10^{-19}}{1.38\times10^{-23}\times2000}}}{AS1000^2\ e^{\frac{-4.52\times1.6\times10^{-19}}{1.38\times10^{-23}\times1000}}} = 9.59\times10^{11}$$

Case 3

T=3000 K

Now, $$\frac{n(T)}{n(1000)} = \frac{AS3000^2\ e^{\frac{-4.52\times1.6\times10^{-19}}{1.38\times10^{-23}\times3000}}}{AS1000^2\ e^{\frac{-4.52\times1.6\times10^{-19}}{1.38\times10^{-23}\times1000}}} = 1.34\times10^{16}$$

6. Question

The saturation current from a thoriated-tungsten cathode at 2000 K is 100 mA. What will be the saturation current for a pure-tungsten cathode of the same surface area operating at the same temperature? The constant A in the Richardson-Dushman equation is 60×10^4 A $m^{-2}K^{-2}$ pure tungsten and 3.0×10^4 A $m^{-2}K^{-2}$ for thoriated tungsten. The work function of pure tungsten is 4.5 eV and that of thoriated tungsten is 2.6 eV.

Answer

According to Richardson-Dushman Equation thermionic current i is

$$i = ne = AST^2\ e^{-\phi/kT}$$

where, n is the thermions emitted, S is the surface area, T is the absolute temperature, k is the Boltzmann constant, A is the constant depend on nature of metal and ϕ is the work function.

Given,

$I_{ttungsten}$=100 mA

T=2000 K

$A_{ttungsten}=3 \times 10^4$ A m^{-2} K^{-2}

$A_{ptungsten}=60\times 10^4$ A m^{-2} K^{-2}

$\Phi_{ttungsten}$ =2.6 eV

$\Phi_{ptungsten}$ =4.5 eV

Now,

$$\frac{I_{ttungsten}}{I_{ptungsten}} = \frac{3 \times 10^4 \times S \times 2000^2\ e^{\frac{-2.6 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 2000}}}{60 \times 10^4 \times S \times 2000^2\ e^{\frac{-4.5 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 2000}}}$$

$$\frac{100}{I_{ptungsten}} = \frac{3 \times 10^4 \times S \times 2000^2\ e^{\frac{-2.6 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 2000}}}{60 \times 10^4 \times S \times 2000^2\ e^{\frac{-4.5 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 2000}}}$$

$$\frac{100}{I_{ptungsten}} = \frac{e^{\frac{(-2.6+4.5) \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 2000}}}{20}$$

$$I_{ptungsten} = \frac{100 \times 20}{e^{\frac{(-2.6+4.52) \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 2000}}} = 2000 \times e^{-11.01} = 33\mu A$$

7. Question

A tungsten cathode and a thoriated-tungsten cathode have the same geometrical dimensions and are operated at the same temperature. The thoriated-tungsten cathode gives 5000 times more current than the other one. Find the operating temperature. Take relevant data from the previous problem.

Answer

According to Richardson-Dushman Equation thermionic current i is

$$i = ne = AST^2\ e^{-\phi/kT}$$

where, n is the thermions emitted, S is the surface area, T is the absolute temperature, k is the Boltzmann constant, A is the constant depend on nature of metal and ϕ is the work function.

Given,

$A_{ttungsten}$=3 × 10^4 A m^{-2} K^{-2}

$A_{ptungsten}$=60× 10^4 A m^{-2} K^{-2}

$\Phi_{ttungsten}$ =2.6 eV

$\Phi_{ptungsten}$ =4.5 eV

$I_{ttungsten}$=5000$I_{ptungsten}$

$$\Rightarrow \frac{I_{ttungsten}}{I_{ptungsten}} = 5000 = \frac{3 \times 10^4 \times S \times T^2\, e^{\frac{-2.6\times1.6\times10^{-19}}{1.38\times10^{-23}\times T}}}{60 \times 10^4 \times S \times T^2\, e^{\frac{-4.5\times1.6\times10^{-19}}{1.38\times10^{-23}\times T}}}$$

$$\Rightarrow 5000 = \frac{e^{\frac{(-2.6+4.5)\times1.6\times10^{-19}}{1.38\times10^{-23}\times T}}}{20}$$

$$\Rightarrow 100000 = e^{\frac{(-2.6+4.5)\times1.6\times10^{-19}}{1.38\times10^{-23}\times T}}$$

Taking log on both sides,

$$11.512 = \frac{22028.98}{T}$$

$$\Rightarrow T = \frac{22028.98}{11.512} = 1913.56\ \mathrm{K}$$

8. Question

If the temperature of a tungsten filament is raised from 2000 K to 2010 K, by what factor does the emission current change? Work function of tungsten is 4.5 eV.

Answer

According to Richardson-Dushman Equation thermionic current i is

$$i\ = ne =\ AST^2\, e^{-\phi/kT}$$

where, n is the thermions emitted, S is the surface area, T is the absolute temperature, k is the Boltzmann constant, A is the constant depend on nature of metal and ϕ is the work function

Given,T1=2000 K

T2=2010 K , Φ =4.5 eV

$$\text{Now,}\frac{I_1}{I_2} = \frac{A \times S \times 2000^2\, e^{\frac{-4.5\times1.6\times10^{-19}}{1.38\times10^{-23}\times2000}}}{A \times S \times 2010^2\, e^{\frac{-4.5\times1.6\times10^{-19}}{1.38\times10^{-23}\times2010}}}$$

$$\frac{I_1}{I_2} = \frac{2000^2\, e^{\frac{-4.5\times1.6\times10^{-19}}{1.38\times10^{-23}}(\frac{1}{2000}-\frac{1}{2010})}}{2010^2} = \frac{2000^2 \times 0.87828}{2010^2} = .869564$$

Required factor is

$$\frac{I_2}{I_1} = \frac{1}{0.87} = 1.14$$

9. Question

The constant A in the Richardson-Dushman equation of tungsten is 60×10^4 A m^{-2} K^{-2}. The work function surface area $2.0 \times 10–5$ m^2 is heated by a 24 W electric equals the energy input by the heater and the temperature becomes constant. Assuming that the cathode radiates like a blackbody, calculate the saturation current due to thermions. Take Stefan constant $=6 \times 10\text{-}^{8}$ W m^{-2} K^{-4}. Assume that the thermions take only a small fraction of the heat supplied.

Answer

Given

$A=60 \times 10^4$ A m^{-2} K^{-2}

$S=2.0 \times 10–5$ m^2

P=24 W

$\sigma=6 \times 10^{-8}$ W m^{-2} K^{-4}

The power radiated by Stefen's law is given by

$P = S\sigma T^4$

$\Rightarrow 24 = 6 \times 10^{-8} \times 2 \times 10^{-5} \times T^4$

$\Rightarrow T^4 = 20 \times 10^{12}$

$\Rightarrow T = 2.1147 \times 10^3 K$

According to Richardson-Dushman Equation thermionic current i is

$i = ne = AST^2 e^{-\frac{\phi}{kT}}$

where, n is the thermions emitted, S is the surface area, T is the absolute temperature, k is the Boltzmann constant, A is the constant depend on nature of metal and ϕ is the work function

$= 60 \times 10^4 \times 2 \times 10^{-5} \times 2114.7^2 \times e^{\frac{-4.5\times1.6\times10^{-19}}{1.38\times10^{-23}\times2114.7}}$

$= 1.034 \times 10^{-3} A$

≈ 1 mA

10. Question

A plate current of 10 mA is obtained when 60 volts are applied across a diode tube. Assuming the Langmuir-Child equation $i_p \propto V_p^{3/2}$ to hold, find the dynamic resistance r_p in this operating condition.

Answer

Given,

$i_p \propto (V_p)^{\frac{3}{2}}$

where i_p is the plate current and V_p is the plate voltage

V= 60 volts

I =10 mA

$\Rightarrow i_p = K(V_p)^{\frac{3}{2}}$ (1) (k is a constant)

Taking derivative on both sides with respect to i_p

$1 = \frac{3}{2} K(V_p)^{\frac{1}{2}} \times \frac{dV_P}{dI_P}$ (2)

Dividing (2)/(1)

$$\frac{1}{i_p} = \frac{3}{2V}\left(\frac{dV_P}{dI_P}\right)_{V_g=\text{constant}}$$

$$\Rightarrow \left(\frac{dV_P}{dI_P}\right) = \frac{2V}{3i_p} = \frac{2 \times 60}{3 \times 10 \times 10^{-3}} = 4K\Omega$$

11. Question

The plate current in a diode is 20 mA when the plate voltage is 50 V or 60 V. What will be the current if the plate voltage is 70V?

Answer

Given the plate current is 20 mA for 50 V and 60 V, i.e. 20 mA is the saturation current.

∴, for a given temperature current remains same for all voltages. . i.e. for 70 V current is 20 mA.

12. Question

The power delivered in the plate circuit of a diode is 1.0 W when the plate voltage is 36 V. Find the power delivered if the plate voltage is increased to 49 V. Assume Langmuir – Child equation to hold.

Answer

Given P1=1 W, V_{P1}= 36 V, V_{P2}= 49 V

We know, $P = VI \Rightarrow P1 = V1 i_{p1} \Rightarrow i_{p1} = \frac{P1}{V1} = \frac{1}{36}$

According to Langmuir-Child equation $i_p \propto V_p^{3/2}$

where i_p is the plate current and V_p is the plate voltage

$$\text{Now,} \frac{i_{p1}}{i_{p2}} = \frac{V_{p1}^{\frac{3}{2}}}{V_{p2}^{\frac{3}{2}}} = \frac{36^{\frac{3}{2}}}{49^{\frac{3}{2}}} = \frac{216}{343}$$

$$\Rightarrow i_{p2} = \frac{343}{36 \times 216} = 0.04411$$

$\therefore P2 = i_{p2} \times V_{P2}$=.04411×49=2.16

W=2.2 W

13. Question

A triode valve operates at V_p = 225 V and V_g = −0.5 V. The plate current remains unchanged if the plate voltage is increased to 250 V and the grid voltage is decreased to −2.5 V. Calculate the amplification factor.

Answer

Given V_{P1}=225 V, V_{P2}=250 V, Vg_1=-0.5, Vg_2=-2.5 V

$$\text{Amplification factor for triode} = -\left(\frac{\triangle V_p}{\triangle V_g}\right)$$

where VT is the change in plate voltage and VT is the change in grid voltage

$$= -\left(\frac{V_{p1} - V_{p2}}{V_{g1} - V_{g2}}\right) = -\left(\frac{225 - 250}{-0.5 + 2.5}\right)$$

$$= \frac{25}{2} = 12.5$$

14. Question

Calculate the amplification factor of a triode valve which has plate resistance of 2 kΩ and transconductance of 2 millimho.

Answer

Given r_P = 2 KΩ = 2× 10^3 (plate resistance)

g_m =2 millimho = 2× 10^{-3} mho(transconductane)

Amplification factor for triode= $\mu = r_p \times g_m = 2 \times 10^3 \times 2 \times 10^{-3} = 4$

15. Question

The dynamic plate resistance of a triode valve is 10 kΩ. Find the change in the plate current if the plate voltage is changed from 200 V to 220 V.

Answer

Given r_p=10 KΩ = 10^4Ω, V_{P1}=200V, V_{P2}=220 V

The dynamic resistance of triode is defined as,

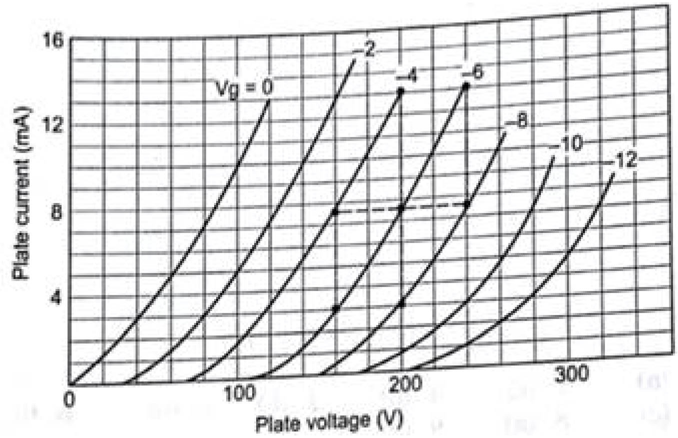
$$r_p = \left(\frac{\Delta V_P}{\Delta I_P}\right)_{V_g=\text{constant}}$$

where ΔV_p is the change in plate voltage and V_g is the grid voltage and ΔI_p is the change in plate current

$$\Rightarrow 10^4 = \frac{220-200}{\Delta I_P} \quad \Rightarrow \Delta I_P = \frac{20}{10^4} = 2\text{mA}$$

16. Question

Find the values of r_p, μ and g_m of a triode operating at plate voltage 200 V and grid voltage −6 V. The plate characteristics are shown in figure.



Answer

The dynamic resistance of triode is defined as,

$$r_p = \left(\frac{\Delta V_P}{\Delta I_P}\right)_{V_g=\text{constant}}$$

where ΔV_p is the change in plate voltage and V_g is the grid voltage and ΔI_p is the change in plate current

From figure, considering the line V_g=-6 V, we get two value of V_P i.e.

V_{P1}=160 V , V_{P2}=240 V , Also i_{p1}=3 mA i_{p2}=13mA

Substituting values in equation we get,

$$r_p = \left(\frac{240 - 160}{(13 - 3) \times 10^{-3}}\right)_{V_g = \text{constant}} = 8\ \text{K}\Omega$$

The mutual inductance g_m of a triode valve is defined as

$$g_m = \left(\frac{\triangle I_P}{\triangle V_g}\right)_{V_p = \text{constant}}$$

Considering two points in the graph where $V_{p=}$200 V we get i_{p1}=13 mA i_{p2}=3mA V_{g1}=-4 V, V_{g2}=-8 V

Substituting values in equation we get.

$$g_m = \left(\frac{(3 - 13) \times 10^{-3}}{-8 + 4}\right)_{V_p = 200V} = 2.5\ \text{milli mho}$$

$$\text{Amplification factor for triode} = \mu = r_p \times g_m = 2.5 \times 8 \times 10^3 \times 10^{-3} = 20$$

17. Question

The plate resistance of a triode is 8 kΩ and the transconductance is 2.5 millimho.

(a) If the plate voltage in increased by 48 V, and the grid voltage is kept constant, what will be the increase in the plate current?

(b) With plate voltage kept constant at this increased value, how much should the grid voltage be decreased in order to bring the plate current back to its initial value?

Answer

Given, r_p=8 kΩ, gm=2.5 millimho

a) CASE 1: $\triangle V_P$=48 V, V_g= constant

The dynamic resistance of triode is defined as,

$$r_p = \left(\frac{\triangle V_P}{\triangle I_P}\right)_{V_g = \text{constant}}$$

where ΔV_p is the change in plate voltage and V_g is the grid voltage and ΔI_p is the change in plate current

substituting the values

$$\Rightarrow 8000 = \frac{48}{\triangle I_P}$$

$$\Rightarrow \triangle I_P = \frac{48}{8000} = 6 \text{ mA}$$

b) CASE 2: g_m=2.5 millimho=.0025 mho, $\triangle I_p$ =6 mA =.006 A

The mutual inductance g_m of a triode valve is defined as

$$g_m = \left(\frac{\triangle I_P}{\triangle V_g}\right)_{V_p=\text{constant}}$$

$$0.0025 = \left(\frac{.006}{\triangle V_g}\right)$$

$$\triangle V_g = \frac{0.006}{.0025} = 2.4\text{V}$$

18. Question

The plate resistance and the amplification factor of a triode are 10 kΩ and 20. The tube is operated at plate voltage 250 V and grid voltage –7.5 V. The plate current is 10 mA

(a) To what value should the grid voltage be changed so as to increase the plate current to 15 mA?

(b) To what value should the plate voltage be changed to take the plate current back to 10 mA?

Answer

Given, r_p=10kΩ, μ=20, V_{P1}=250 V. Vg_1=-7.5 V, ip_1=10 mA

a) CASE 1: i_{p2}=15 mA. V_P= Constant, Vg_2=? i_{p1}=10 mA

We know, $\text{Amplification factor for triode} = \mu = r_p \times g_m$

where r_p is the plate resistance and g_m is the trans-conductance

$$g_m = \frac{20}{10000} = 2 \times 10^{-3} \text{ mho}$$

Now,

$$g_m = \left(\frac{\triangle I_P}{\triangle V_g}\right)_{V_p=\text{constant}}$$

where ΔV_g is the change in grid voltage and V_p is the plate voltage and ΔI_p is the change in plate current

$$0.002 = \left(\frac{(15-10)\times 10^{-3}}{\triangle V_g}\right)$$

$$\triangle V_g = \frac{0.005}{.002} = 2.5V$$

$$V_{g2} - V_{g1} = 2.5\ V$$

$$V_{g2} = 2.5 - 7.5 = 5\ V$$

b)CASE 2: V_{P3}=?,i_{p3}=10 mA, i_{p2}=15mA, i_{p3}=10mA

The dynamic resistance of triode is defined as,

$$r_p = \left(\frac{\triangle V_P}{\triangle I_P}\right)_{V_g=\text{constant}}$$

where ΔV_p is the change in plate voltage and V_g is the grid voltage and ΔI_p is the change in plate current

$$\Rightarrow 10000 = \frac{\triangle V_P}{(10-15)\times 10^{-3}}$$

$$\Rightarrow \triangle V_P = -50$$

$$\Rightarrow V_{p3}\text{-}V_{p2} = -50$$

$\Rightarrow$ $V_{p3} = 200$ V, required voltage

19. Question

The plate current, plate voltage and grid voltage of a 6F6 triode tube are related as

$I_p = 41(V_p + 7\ V_g)^{1.41}$, Where V_p and V_g are in volts and ip in microamperes. The tube is operated at V_p = 250 V, V_g = –20 V. Calculate

(a) the tube current,

(b) the plate resistance,

(c) the mutual conductance and

(d) the amplification factor.

Answer

a) Given, V_P = 250 V, V_g = –20 V

Also, $i_P = 41(V_P + 7V_g)^{1.41}$

$$i_P = 41(250 - 140)^{1.41} = 41 \times (110)^{1.41} = 30984\ \mu A = 30\ mA$$

b) Differentiating the given equation with respect to i_p keeping Vg constant.

$$1 = 41 \times 1.41(V_P + 7V_g)^{0.41} \times (dV_P/di_p)$$

The dynamic resistance of triode is defined as,

$$r_p = \left(\frac{dV_P}{dI_P}\right)_{V_g=constant} = \frac{10^6}{41 \times 1.41 \times 110^{.41}} = 2.5 \times 10^3 = 2.5\ K\Omega$$

c) Differentiating the given equation with respect to V_g keeping V_p constant

$$\frac{di_p}{dV_p} = 41 \times 1.41(V_P + 7V_g)^{0.41} \times (7)$$

$$g_m = \left(\frac{dI_P}{dV_g}\right)_{V_p=constant} \Rightarrow 41 \times 1.41 \times 110^{.41} \times 7 = 2780.18\ \mu\ mho$$
$$= 2.78\ millimho$$

d) Amplification factor for triode $= \mu = r_p \times g_m$

where r_p is the plate resistance and g_m is the trans-conductance

$= 2.5 \times 10^3 \times 2.78 \times 10^{-3}$

$= 6.95 \approx 7$

20. Question

The plate current in a triode can be written as

$i_p = k\left(V_g + \frac{V_p}{\mu}\right)^{3/2}$. Show that the mutual conductance is proportional to the cube root of the plate current.

Answer

Given:

$$i_p = k\left(V_g + \frac{V_P}{\mu}\right)^{3/2}$$

g_m is the mutual conductance, i_p is the plate current, V_p is the plate current and V_g is the grid voltage.

$$g_m = \frac{di_p}{dV_g} = \frac{3}{2}k\left(V_g + \frac{V_P}{\mu}\right)^{1/2}$$

Taking cube on both sides,

$$g_m^3 = \frac{27}{8}k^3\left(V_g + \frac{V_P}{\mu}\right)^{\frac{3}{2}}$$

$g_m^3 = \frac{27}{8}k^2 i_p \Rightarrow g_m \propto i_p^{1/3}$ hence proved

21. Question

A triode has mutual conductance = 2.0 millimho and plate resistance = 20 kΩ. It is desired to amplify a signal by a factor of 30. What load resistance should be added in the circuit?

Answer

Given g_m=2millimho=2×10^{-3}mho, rP=20 kΩ, A=30

Here,$\mu = r_p \times g_m$

where r_p is the plate resistance and g_m is the trans-conductance

$$= 20 \times 10^3 \times 2 \times 10^3 = 40$$

We know,$A = \frac{\mu}{1 + \frac{r_p}{R_L}}$

where A is the voltage gain, μ is the amplification factor, R_L is the load resistance and r_p is the plate resistance

$$30 = \frac{40}{1 + \frac{20000}{R_L}}$$

$$\Rightarrow 1 + \frac{20000}{R_L} = \frac{4}{3} \Rightarrow \frac{20000}{R_L} = \frac{1}{3} \Rightarrow R_L = 60\ K\Omega$$

22. Question

The gain factor of an amplifier is increased from 10 to 12 as the load resistance is changed from 4 kΩ to 8 KΩ. Calculate (a) the amplification factor and (b) the plate resistance.

Answer

$A = \frac{\mu}{1+\frac{r_p}{R_L}}$ ...(i)

where A is the voltage gain, μ is the amplification factor, R_L is the load resistance and r_p is the plate resistance

Given:

A_1=10, R_{l1} = 4kΩ

A_2=12, R_{l2} = 8kΩ

Putting these two values in equation (i)

$$10 = \frac{u}{1 + \frac{r_p}{4000}}$$

$$10(4000 + r_p) = 4000\mu$$

We get a linear equation in 2 variables (r_p and μ)

$$4000\mu - 10r_p = 40000$$

$$400\mu - r_p = 4000 \text{ ...(ii)}$$

We will get another equation by substituting the values of A_2 and R_{l2} is equation (i)

$$12 = \frac{\mu}{1 + \frac{r_p}{8000}}$$

$$12(8000 + r_p) = 8000\mu$$

$$8000\mu - 12r_p = 96000 \text{ ... (iii)}$$

Solving (ii) and (iii) to find the values amplification factor and the plate resistance.

$$400\mu - r_p = 4000 \ \& \ 8000\mu - 12r_p = 96000$$

From (ii)

$$r_p = 400\mu - 4000 \text{ ...(iv)}$$

Substituting (iv) in (iii)

$$8000\mu - 12(400\mu - 4000) = 96000$$

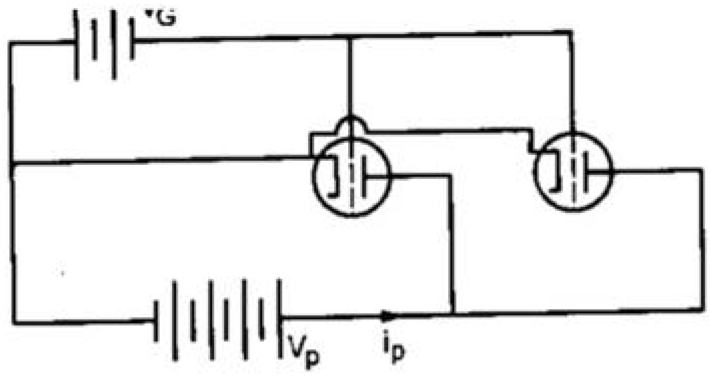
$$3200\mu = 48000$$

$$\mu = 15$$

Using μ =15, the value of r_p is 2000Ω or 2 kΩ

23. Question

Figure shows two identical triode tubes connected in parallel. The anodes are connected together, the grids are connected together and the cathodes are connected together. Show that the equivalent plate resistance is half to the individual plate resistance. The equivalent mutual conductance is double the individual mutual conductance and the equivalent amplification factor is the same as the individual amplification factor



Answer

Given the anodes are connected together, the grids are connected together and the cathodes are connected together i.e. two triodes have same voltage and same current which means $r_{P1} = r_{P2}$=r

Here the equivalent resistance,

$$R = \frac{(r_{P1} \times r_{P2})}{(r_{p1} + r_{p2})} = \frac{r^{\ 2}}{2r} = \frac{r}{2}$$

i.e., the equivalent plate resistance is half to the individual plate resistance.

Let g_{m1} and g_{m2} be the individual conductance.

From figure, g_{m1} = g_{m1} = g. As two triodes are parallel i.e. equivalent conductance

$$G = (g_{m1} + g_{m2}) = 2g$$

i.e. The equivalent mutual conductance is double the individual mutual conductance

Now, $\mu 1 = g_{m1} r_{p1} = gr$

Also, $\mu 2 = g_{m2} r_{p2} = gr$

equvalent amplification factor, $\mu = RG = \frac{r}{2} \times 2g = rg$

I.e. the equivalent amplification factor is the same as the individual amplification factor