SEMICONDUCTOR DIODES AND TRANSISTORS

PROGRAMED INSTRUCTION

MANUFACTURERS OF CATHODE-RAY OSCILLOSCOPES

VOLUME 2
DIODE DEVICES

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SEMICONDUCTOR DIODES AND TRANSISTORS

VOLUME 2

DIODE DEVICES

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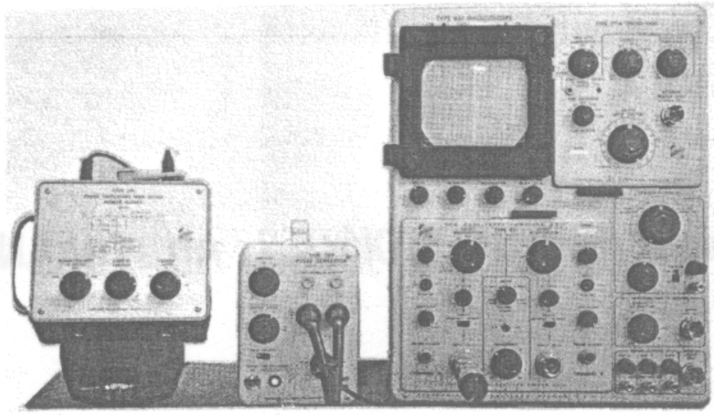

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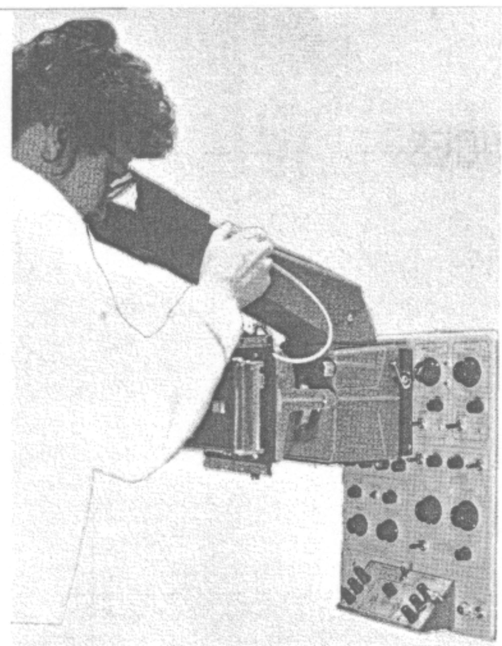
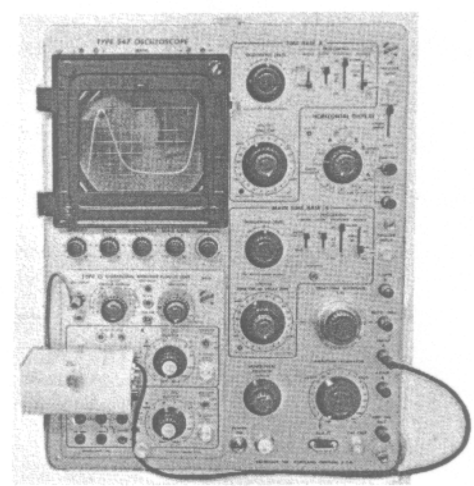




MARKETING TECHNICAL TRAINING

SEMICONDUCTOR DIODES AND TRANSISTORS

VOLUME 2

DIODE DEVICES

This volume is about the theory of operation and construction of semiconductor diode devices. It discusses their characteristics and parameters and methods of measuring them. It further discusses some typical uses and effects of external environment, including applied energy and surrounding temperature.

PREREQUISITES:

This volume assumes the reader's successful completion of Semiconductor Diodes and Transistors - Volume 1 - Basic Semiconductors and Diodes, or its equivalent. If the reader does not have this background, some outside study is indicated before starting this volume.

BROAD OBJECTIVES:

On successful completion of this volume, the reader will have applied the knowledge gained from Volume 1, Basic Semiconductors and Diodes, to the study of Diode Devices and shall have knowledge of the diode devices discussed in this volume. He shall also have prepared himself and met one of the prerequisites for Volume 3 and 4 of this semiconductor program series.

SPECIFIC OBJECTIVES:

On successful completion of this volume, the reader will be able to do the following:

1. Recall that doping by diffusion is the process of heating the basic material while surrounding it with dopents in a gaseous form and that the dopents are taken into the basic material during the process, allowing close control of doping.

2. Recall that silicon rectifiers can be made by diffusing a junction into high resistivity silicon and that this allows close control of the diodes characteristics.

3. Recall that diodes constructed of such materials as copper oxide, selenium and germanium are limited to less than 100° centigrade maximum operating temperature, while a diode made of silicon can operate to 175° centigrade.

4. Recall that silicon rectifiers have the added advantages over other semiconductor rectifiers of high reverse breakdown (1000 volts), low reverse leakage current and high forward current handling capabilities due to the ability to withstand high densities of electrical charge.

5. Recall that a silicon PN junction can conduct heavily when forward biased, but that only a small current flows when it is reverse biased. Recall that forward bias current is limited by the series resistance in the circuit.

6. Recall that a forward biased junction has a low voltage across it, and that the forward voltage at low currents varies inversely with changes in temperature and is said to have a negative temperature coefficient of voltage.

7. Recall that the application of an excessive reverse voltage will result in the diode entering avalanche breakdown (above 6 volts) or tunneling breakdown (below 6 volts), but that tunneling breakdown only occurs in very heavily doped junctions.

8. Recall that a junction in avalanche breakdown has a positive temperature coefficient of voltage and that a junction that is in tunnel breakdown has a negative temperature coefficient of voltage.

9. Recall that an a-c voltage applied across a silicon rectifier will alternately forward bias and reverse bias the junction, and that most of the a-c voltage is across the diode during the period that it is reverse biased.

10. Recall that a silicon diode in series with a load and an a-c source will result in pulsating d-c being supplied to the load, and that reversing the diode will reverse the polarity of pulsating d-c.

11. Recall that the maximum reverse bias voltage that can be applied to the device at a given temperature without breakdown occuring is termed Peak Inverse Voltage and that the peak inverse voltage rating of the diode should be greater than the maximum expected peak input a-c voltage when the diode is employed in an a-c circuit.

12. Recognize diode rectifier characteristics, including Peak Inverse Voltage, Average Half Wave Rectified Current, Maximum Forward Voltage Drop, Maximum Reverse Current, Peak One Cycle Surge Current, Maximum Operating and Storage Temperature, and be able to define each of these characteristics.

13. Recall that the maximum forward voltage drop of the diode and forward bias current can be used to find power dissipation to determine if the diode is working within its limits.

14. Recall that the maximum reverse current and peak inverse voltage may be used to determine the reverse resistance of the diode.

15. Recall that the maximum power dissipation is limited by the maximum allowable junction temperature, the ambient temperature, and the total thermal resistance for both the forward and reverse biased conditions.

16. Recall that using an external heat sink with a diode reduces the total thermal resistance and for a given diode and ambient temperature, increases the maximum power dissipation capabilities of the diode.

17. Recall that the Peak Inverse Voltage rating may be increased by stacking silicon rectifiers in series, but care must be taken to have equal reverse resistances and storage times in all the diodes used, or to compensate the circuit by

adding shunt resistors and/or capacitors.

18. Recall that the shunting compensating resistors used with series stacked rectifiers should be made as small as possible while still offering a high resistance to reverse current and typical values are about one half the reverse resistance of the diode.

19. Recall that the differences in storage times in stacked rectifiers can be compensated with shunt capacitors and that the value of shunting capacitor can be calculated using the formula:

$$C = \frac{t_{s\,(total)}}{R_L}$$

20. Recall that high voltage rectifier stacks are available with diodes cut from the same crystal to minimize the differences involved when dealing with peak inverse voltage.

21. Recall that a diode at equilibrium has an area about the junction that is depleted of carriers and that the N and P regions separated by the depletion region can serve as a capacitor that can have its capacity varied by varying the bias voltage applied.

22. Recall that specially made diodes are in use as voltage variable capacitors and recognize the symbol for the voltage variable capacitor, and be able to name the parts.

23. Recognize an example of a zener diode as a diffused silicon P-N junction operating in the avalanche breakdown region above 6 volts and the tunnel breakdown region below 6 volts (typically).

24. Recall that rigid control of the diffusion of impurities in zener diodes is a method that allows close tolerance of breakdown voltage levels and that breakdown voltages up to several hundred volts are obtainable.

25. Recall that the voltage across the diode terminals changes very little over a wide range of currents once into the avalanche breakdown region, and that the point of breakdown is termed the zener knee.

26. Recognize the voltage versus current curve for a zener diode and recall that the term zener diode is misleading because a great number of zener diodes work in the avalanche breakdown region (above 6 volts).

27. Recall that with a series impedance to drop the added voltage and an applied voltage above the zener knee, the zener diode will maintain a near constant voltage across itself.

28. Recall that the power limiting factors for zener diodes are the same as for any semiconductor diode and be able to recognize the symbol for a zener diode, and indicate the direction of electron current when the diode is in reverse breakdown.

29. Recognize a basic zener diode circuit and compare its operation to the operation

of the gaseous V-R tube basic circuit.

30. Recall that the minimum V-R tube voltage is limited to about 70 volts, while zener diodes are available over the entire voltage range up to several hundred volts.

31. Recall that the gas V-R tube is limited between two current levels set by the internal geometry of the tube, while the zener diode current is limited by the junction geometry and thermal dissipation, allowing a wide range of zener voltages and power dissipations.

32. Recall that the noise in a zener diode is of the same magnitude as that generated by the gaseous discharge in the V-R tube, but that a shunt capacitance of 0.01 to 0.1 μfd or more will reduce the noise by a factor of 10 in a zener diode, while this method of noise suppression is impractical with the V-R tube because it breaks into relaxation oscillations.

33. Recall that a V-R tube will have voltage drift for several minutes when first turned on, while the zener diode has no measureable drift when turned on.

34. Recall that the zener diode in avalanche has a positive temperature coefficient of voltage, while a forward biased diode has a negative temperature coefficient of voltage, and that forward biased diodes may be used to temperature compensate zener diodes.

35. Recall that series opposed zeners find use in a-c circuits and that they tend to temperature compensate each others voltage as a result of opposing temperature coefficients of voltage.

36. Recall that a zener diode has similar specifications to the rectifier with the added zener information, and be able to read a specification sheet for a zener diode and determine its characteristics and limitations.

37. Recall that some diodes are designed for rectifier service that have controlled doping for a reverse breakdown point that offers, along with rectification, peak inverse limiting.

38. Recall that as the doping levels in a diode are increased, the voltage at which the diode enters reverse breakdown is reduced. Recall that a level of doping can be reached where tunnel breakdown occurs with forward voltage applied, and that tunnel diodes and backward diodes are this heavily doped.

39. Recognize the energy band diagrams of a heavily doped junction where tunneling is enhanced, and be able to explain the results of biasing the junction with forward and reverse voltage.

40. Recognize the portion of the tunnel diode EI curve which represents a negative resistance or conductance, and be able to explain the tunnel diode EI curve with the use of energy band diagrams.

41. Recognize the parameters of a tunnel diode to include Peak Current (I_p), Valley Current (I_v), Peak Voltage (V_p), and Valley Voltage (V_v), and be able to define

them. Recall the factors that determine the magnitude of these parameters.

42. Make measurements on the tunnel diode EI curve using the cathode ray tube display of the type 575 Transistor-Curve Tracer, determining approximate negative conductance by use of the formula:

$$-gd \approx \frac{2\,(I_p - I_v)}{V_v - V_p}$$

and recall that a separate variable resistor may be added to aid in the measurement.

43. Recall that the negative conductance characteristic of the tunnel diode allows amplification with a <u>two</u> terminal device and recognize the symbols for a tunnel diode, and be able to name the parts.

44. Recall that since the tunnel diode must remain in the negative resistance region to serve as a linear amplifier, the current swing of a tunnel diode is limited between I_p and I_v, and the voltage swing is limited between V_p and V_v.

45. Recall that for amplifier service, the load line when plotted on the tunnel diode EI curve must have a steeper slope than the negative resistance region of tunnel diode curve, therefore, the total positive resistance must be less than the absolute value of the diodes negative resistance.

46. Recognize a basic series tunnel diode amplifier circuit and explain the amplifier action by use of the tunnel diode curve or the parameters and circuit components. Be able to predict voltage gain using the formula:

$$A_v = \frac{r_L}{r_L + (-r_d)}$$

where A_v is voltage gain, r_L is the positive resistance, and $-r_d$ is the negative resistance of the tunnel diode.

47. Recognize a basic parallel tunnel diode amplifier circuit and explain the amplifier action using the tunnel diode parameters and circuit components. Be able to predict the current gain using the formula:

$$Ai = \frac{g_L}{g_L + (-g_d)}$$

where Ai is current gain, g_L is the conductance of the positive resistance, and $-g_d$ is the negative conductance of the tunnel diode.

48. Recall that sufficient stray or lumped reactance will result in the tunnel diode breaking into oscillations and, therefore, the layout for low frequency circuits is not feasible.

49. Recall that a total series positive resistance greater than the negative

resistance of the tunnel diode results in the tunnel diode acting as a switch, and be able to explain the switching action for current drive and voltage using the tunnel diode EI curve and loadlines.

50. Recall the circuit requirements for the three modes of operation of the tunnel diode; switching, stable, and oscillations.

51. Recall that special tunnel diodes constructed to have low peak currents and to conduct heavily with a reverse bias applied are called "Backward Diodes" and that they have the advantage of a much lower conducting voltage drop than the conventional diode.

52. Recall that fast switching diodes are constructed for low capacity and stored charge to enhance fast forward and reverse recovery.

53. Recall the definition of the parameters and specifications of a fast switching diode, and recall that maximum current, voltage, and power dissipation are limited by the same factors as all diodes.

54. Recall that a reduction of the minority carrier lifetime will reduce storage time and reduce switching time for a given forward current.

55. Recall the definition of the forward and reverse recovery parameters of fast switching diodes, and relate them to the display on the cathode ray tube in a sampling system when using the Type 291 Diode Switching Time Tester.

56. Recall that the "Snap-Off" diode has a controlled steep falling portion of the reverse recovery waveform and that this is accomplished by controlling minority carrier lifetime and shaping reverse recovery in the doping process.

57. Recall that the Snap-Off diode, when switched from forward conduction to a reverse bias condition, will continue to conduct for the duration of the stored charge, but will cut-off or snap-off in a fractional nanosecond.

58. Recall that using the snap-off portion of the snap-off diodes characteristic as the leading edge of a generated pulse results in a fractional nanosecond rise-time pulse.

59. Recognize the construction of symbols for the EI curve of the four layer diode, and be able to explain its operation using its EI curve.

60. Recognize the construction of, the symbols for, and the EI curve of the Silicon Control Rectifier, and recall the effects of changing the magnitude of the applied gate current.

The reader will know when he has met these objectives by correctly answering 90% of the questions in the self test at the back of this volume.

INSTRUCTIONS

The material in this volume is presented in a series of numbered statements. Each numbered statement is termed a "frame" and each group of frames bearing the same first number (3, 3.1, 3.2, etc.) is termed a "set". The answer to each frame is in a small box in the lower left hand corner of the following frame.

The material is presented in three types of frames within a set; the "gating frame", the "teaching frame", and the "criterion frame".

The first frame in each set is the gating frame. Cover the following frame which contains the answers with the mask provided. Read the frame carefully, studying any diagrams that are provided, and fill in the blanks. Do not look at the answer until you fill in the blanks.

Since there is no clue given to the answer, you must know something about the material to fill in the blanks in the gating frame. If you can answer the gating frame and you are sure of the material, skip to the next gating frame and continue. The gating frames are designed to give the student that is familiar with the subject an indication of the information contained in the set and allow him to skip the set if he feels he knows the information covered.

If you cannot answer the gating frame, continue with the teaching frames in that set, covering the answers and filling in the blanks. You will find clues to the answers in the teaching frames or their diagrams.

The last frame in each set will have two (**) asterisks following the number. This is the criterion frame and, once again, no clue is given to the answers. The preceding teaching frames should have provided the information needed to work the criterion frame. If your answer is wrong, go back and review the material in the teaching frames.

You may progress through the program at any speed you select. Don't miss an opportunity to review the material in a set if you can answer the gating frame, but are a little hazy on the subject.

This is not a test. You are not being graded and you are not expected to be able to answer the gating frames unless you have the knowledge to let you skip a set. If you answer the teaching frames or the criterion frames incorrectly, don't be concerned, but go back and review the previous frame or frames as needed. Answer from the information presented and, if your answer does not match, review the material before going on.

If you would like to measure your gains with this volume, answer the self test in the back of the volume without grading it, before proceeding into the programed material. After completing the programed material, answer the self test again grading both attempts. This will give an indication of the gains realized with this volume.

Do each set in sequence, starting with set 1.

If you are ready to proceed with the programed material, turn to the first gating frame - - -

1 Doping or adding impurities to the basic semiconductor by ______________ is the process of heating the basic semiconductor while surrounding it with the impurities in a _________ form. The impurities are taken into the basic semiconductor during the process and this method of doping gives the advantage of close __________________ of impurity levels.

1.1 Raising the temperature of a material increases the molecular and atomic activity. A temperature is reached at which impurities can enter the structure being heated.

diffusion
gaseous
control

1.2 Doping by the diffusion process involves surrounding the material to be doped with the impurities in a gaseous form. The impurities will "diffuse" or spread into the material when it is __________________ to the proper temperature.

no answer needed

1.3 By controlling the amount of impurities gas present, and by masking off or protecting the areas not to be doped, a close control of doping by _____________________ can be obtained.

heated

1.4 Figure 1 shows a sketch of the process of doping by diffusion. The diffused area and the basic structure form a PN ______________________.

diffusion

1.5 Covering part of the semiconductor to be doped with a material that will not pass the impurity gas is termed "masking" the semiconductor for diffusion. Diffusion of impurities will take place only where the semiconductor is not _________________.

junction or diode

1.6 Masking, limiting the impurity gas present, and setting the temperature allows close ________________ of doping by _________________________.

masked

1.7** Causing gaseous impurities to enter a piece of semiconductor by applying heat is termed doping by the _______________ process. Good control of doping can be obtained by controlling the temperature, the amount of ______________________ gas present, and by ____________________ the basic crystal.

control
diffusion

1.8 END OF SET

diffusion
impurity
masking

2 Silicon rectifiers are constructed by __________ a junction into __________ (high, low) resistivity silicon. This process allows close __________ of the diodes characteristics. Silicon diodes can operate up to __________ degrees centigrade, while other semiconductor diodes are limited to below __________ degrees centigrade.

2.1 Silicon rectifiers are PN junctions that have been diffused into a silicon crystal.

diffusing
high
control
175
100

2.2 Starting with high resistivity silicon and diffusing in the desired junction allows close __________ of the diodes characteristics.

no answer needed

2.3 Damage to the junction occurs at or above 100 degree centigrade in most semiconductor junctions. In __________ junctions, however, this does not occur below approximately 175 degrees centigrade.

control, tolerance, etc.

2.4 Maximum allowable junction operating temperature is approximately ________________ degrees centigrade for germanium diodes, and __________ degrees centigrade for silicon diodes.

silicon

2.5 Since silicon diodes can tolerate a higher junction temperature, they can handle ___________ (more, less) power for a given ambient temperature and total thermal resistance.

100
175

2.6 Germanium diodes are harmed at ______________ (higher, lower) operating temperatures than silicon.

more

2.7** Diffused junction techniques in high resistivity silicon allows close control of silicon rectifier _______________. It is possible for a ______________ diode to tolerate a junction operating temperature of 150 degrees centigrade, but not a __________________ diode.

lower

2.8 END OF SET

characteristics, parameters, etc.
silicon
Germanium (or most semiconductors)

3 Silicon rectifiers designed for high power, low frequency service (below 500 cycles) have the advantage over other semiconductor rectifiers of ____________ reverse breakdown voltage, ____________ reverse leakage currents, and _______________ forward current handling capabilities.

3.1 Germanium and other semiconductor diodes generally have to be stacked in series for a high reverse breakdown voltage rating, while silicon diodes have been made with reverse breakdown voltages to 1000 volts and beyond.

higher
lower
higher

3.2 At a given temperature, there will be less minority carriers present in a silicon diode than other semiconductor diodes. Diode reverse current magnitude is dependent on the number of ________________ carriers present in the two sides.

no answer needed

3.3 At a given temperature, there will be less reverse bias current in a ___________ diode than other semiconductor diodes, since there are less ___________ carriers available.

minority

3.4 Two advantages of silicon rectifiers over other semiconductor types are higher ____________ breakdown voltage and lower ____________ bias current.

silicon
minority

3.5 Silicon diodes can withstand higher densities of electrical charge than other semiconductor diodes. Germanium diodes can handle ____________ (more, less) forward current at a given temperature than silicon diodes.

reverse
reverse

3.6 Silicon diodes can handle more heat producing power at the junction at a given ambient (surrounding air) temperature because the maximum allowable junction ____________ is higher than other semiconductor diodes.

less

3.7** Silicon diodes lend themselves well to rectifier service since they can withstand high ____________ bias voltages, high ____________ bias currents while offering low ____________ bias currents.

temperature

3.8 END OF SET

reverse
forward
reverse

4 When a silicon diode is forward biased by a voltage greater than approximately 1 volt, the ________________ is limited by the series resistance in the circuit. Very little current flows when the diode is reverse biased until the ________________ breakdown point is reached and then ________________ is limited by the series resistance in the circuit. The point at which reverse breakdown occurs is ____________ dependent.

4.1 Figure 4A shows the forward characteristic of a silicon diode. The forward voltage point at which there is a significant increase in forward current is approximately ___________ volts of forward voltage.

current
avalanche (reverse)
current
temperature

4.2 The only difference in the two measurements shown in figure 4A is the resistance in series with the diode. With a greater resistance in series with the diode, __________ (more, less) current can flow for a given applied voltage.

0.6

4.3 In figure 4A, with a series resistance of 50 ohms and the applied voltage shown, a maximum of about ________ma of forward current can flow. With a series resistance of 100 ohms, a maximum of only about ________ma of forward current can flow with the same applied voltage.

less

4.4 Current is primarily limited by the ____________ ______________ once the diode has been essentially turned on in the forward direction, and the current will vary ____________________ (directly, inversely) as the value of series resistance varies.

250
125

4.5 With reverse voltage applied, only a small current flows, limited by the number of ___________________ carriers available.

series resistance
inversely

4.6 When the avalanche breakdown point is reached, multiplication of carriers results in the current increasing sharply. Once into avalanche, the current is primarily limited by the series ______________ in the circuit.

minority

4.7 When used as a rectifier, the voltage point at which avalanche breakdown occurs, limits the _______________ a-c voltage which can be applied to the diode.

resistance

4.8 Figure 4B shows a test set-up to measure the reverse breakdown of a silicon diode. The diode shown breaks down at about 1480 volts of reverse voltage.

peak (maximum)

4.9 Mod 122C is a modification to the Type 575 to extend its voltage range to 1.5K volts to observe the reverse ________________ characteristics of diodes and transistors.

no answer needed

4.10 The diode shown in figure 4B will break down at ________________ (the same, a different) reverse voltage if measured at a different surrounding air temperature.

breakdown

4.11 Since a change in temperature effects the reverse breakdown voltage, the ____________ should be specified when stating the maximum reverse voltage that can be applied to a diode.

a different

4.12** Once effectively turned on by forward voltage, the diode current is primarily limited by the ________________ in series. Only thermally generated ________________ carrier current flows when the diode is reverse biased until avalanche breakdown is reached. Once in avalanche breakdown, current is limited primarily by the ___________ ____________ in the circuit and the voltage point at which breakdown occurs is ____________________ dependent.

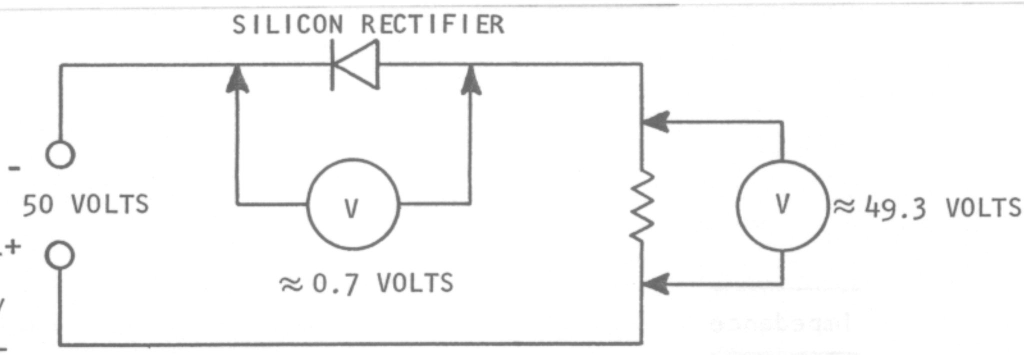
temperature

4.13 END OF SET

resistance
minority
series resistance
temperature

5 With forward voltage applied and significant forward conduction, approximately __________ volts appear across a silicon rectifier at room temperature. At low currents, this voltage will vary __________ with temperature changes, and the diode is said to have a __________ temperature coefficient of voltage.

5.1 At 25 degrees centigrade, a forward biased silicon rectifier has approximately 0.7 volts across its terminals and the remainder of the applied voltage appears across the series impedance in the circuit.



0.7
inversely
negative

5.2 The voltage across the series impedance of the circuit will be the difference between applied voltage and the voltage across the __________.

no answer needed

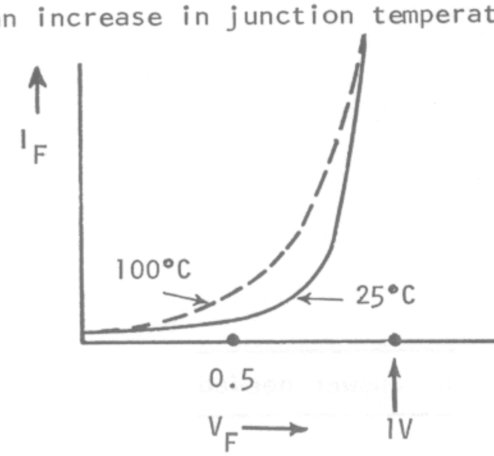
5.3 The current in the circuit will be equal to the voltage across the series impedance divided by the series impedance. The current will be primarily limited by the series ____________________ of the circuit when the diode is in forward conduction.

diode

5.4 When forward voltage is applied to a diode, the total circuit series ____________________ must limit the forward bias current below the maximum allowable forward current of the diode.

impedance

5.5 The voltage across the diode will change with a change in temperature. The diagram indicates that, at low forward currents, the voltage across the diode will ____________ with an increase in junction temperature.



impedance

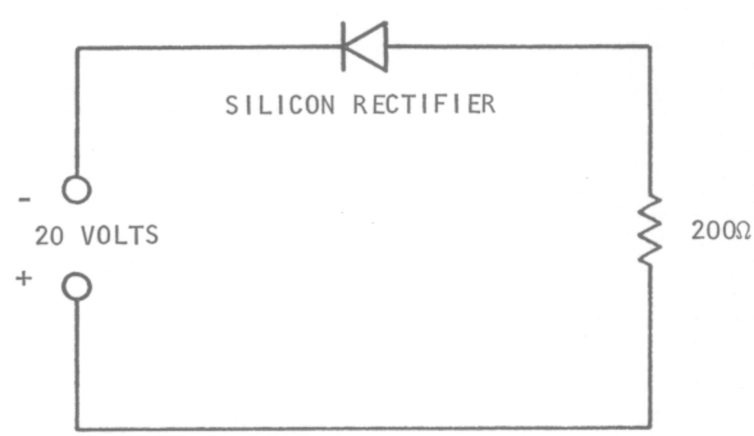
5.6 The diode is said to have a negative temperature coefficient of voltage at low forward currents. The forward voltage drop of the diode goes ________ with a decrease in junction temperature.
(up, down)

decrease

5.7 Since the forward voltage drop varies inversely as the temperature varies at low currents in a silicon rectifier, it is said to have a ________ temperature ________ of voltage.

up

5.8 The forward current in the circuit shown is approximately ________.



negative
coefficient

5.9** The forward biased silicon rectifier has approximately __________ volts dropped across the diode and the remainder of the voltage is across the series impedance of the circuit. The forward voltage across the diode varies ________________ (directly, inversely) with temperature changes, and the diode is said to have a __________ temperature coefficient of voltage when forward biased.

---

considering 0.7 volts across the diode and 19.3 volts across 200 ohm,

$$I \approx \frac{19.3V}{200\Omega} \approx 96.5 \text{ ma}$$

OR neglecting the drop across the diode,

$$I \approx \frac{20V}{200\Omega} \approx 100 \text{ ma}$$

5.10 END OF SET

0.7
inversely
negative

6 Heavily doped junctions with reverse breakdown voltages below 6 volts have a ____________ temperature coefficient of voltage in the breakdown region, and lighter doped junctions with breakdown voltages above 6 volts have a ____________ temperature coefficient of voltage in the breakdown region.

6.1 An increase in temperature increases the voltage requirements to cause avalanche breakdown in a silicon rectifier. Avalanche breakdown occurs at reverse voltages ____________ 6 volts.
(above, below)

negative
positive

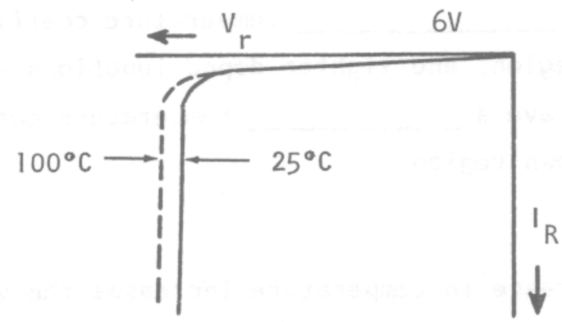
6.2 Tunnel or zener breakdown occurs in heavily doped junctions with reverse breakdown voltages ____________ 6 volts.
(above, below)

above

6.3 An increase in temperature causes a decrease in the voltage across a diode in tunnel breakdown, and it is said to have a ____________ temperature coefficient of voltage when operated in tunnel breakdown.

below

6.4 A silicon rectifier in avalanche breakdown is said to have a __________ temperature coefficient of voltage, and a decrease in temperature results in a __________ in the voltage across the diode.



negative

6.5 A diode in avalanche breakdown will have greater than 6 volts across the diode, and a positive temperature __________ __________ __________.

positive
decrease

6.6 A diode in tunnel breakdown will have less than 6 volts across the diode, and a __________ temperature coefficient of voltage.

coefficient
of
voltage

6.7** Voltage across the diode varies directly with temperature when the diode is in the breakdown region ____________ (above, below) 6 volts, and the voltage across the diode varies inversely with temperature when the diode is in breakdown ____________ (above, below) 6 volts.

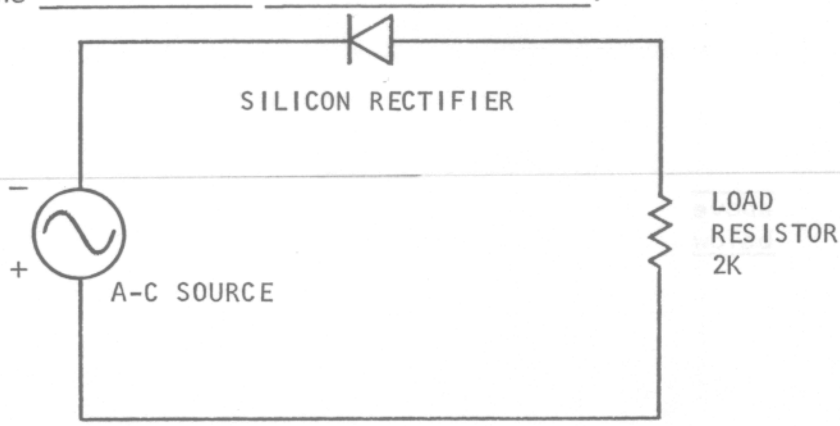
negative

6.8 END OF SET

above
below

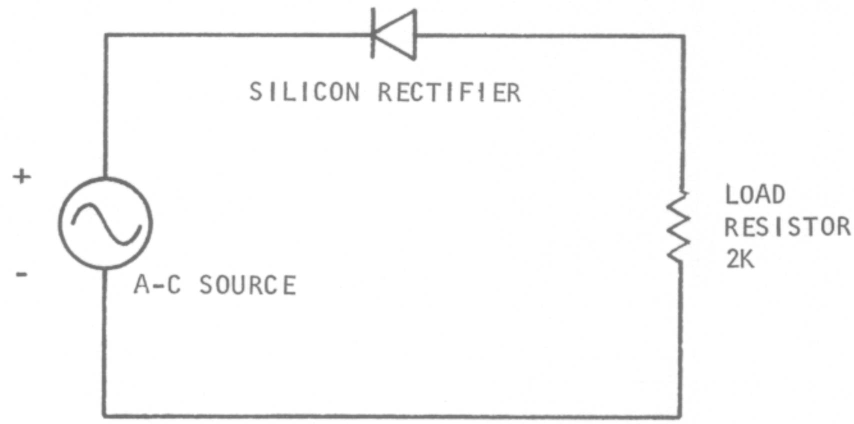
7 Placing a silicon rectifier in series with an a-c source and a load resistance results in the a-c source alternately ________________ and ________________ biasing the diode on alternate half cycles and delivering pulsating ________________ to the resistance. Reversing the connections on the diode reverses the ______________ of the voltage across the load resistance.

7.1 The instantaneous polarity of the a-c source shown will ________________ bias the diode and result in the greatest portion of the applied voltage being across the ____________ ________________.



forward
reverse
d-c
polarity

7.2 The instantaneous polarity of the a-c source shown will ________________ bias the diode and result in the greatest portion of the applied voltage appearing across the ______________ ______________.



forward
load resistor

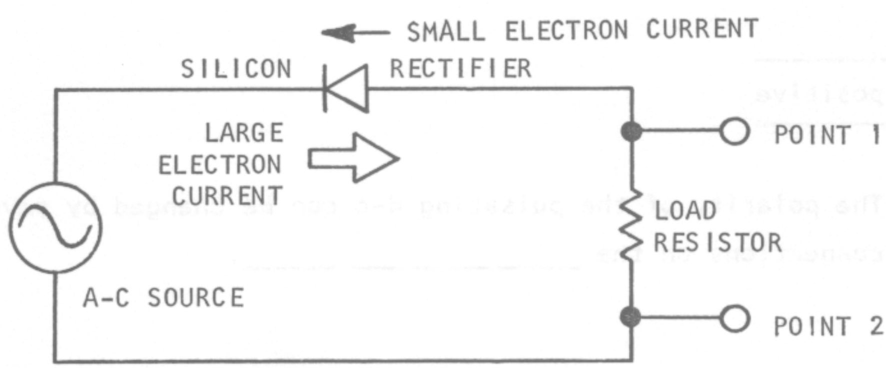
7.3 A reverse biased diode __________ an open circuit and has __________ current flowing.
(is, is not) (some, no)

reverse
silicon rectifier or diode

7.4 With reverse current flowing when the diode is reverse biased, there will be some voltage across the load. This voltage will be proportional to the amount of reverse ______________.

is not
some

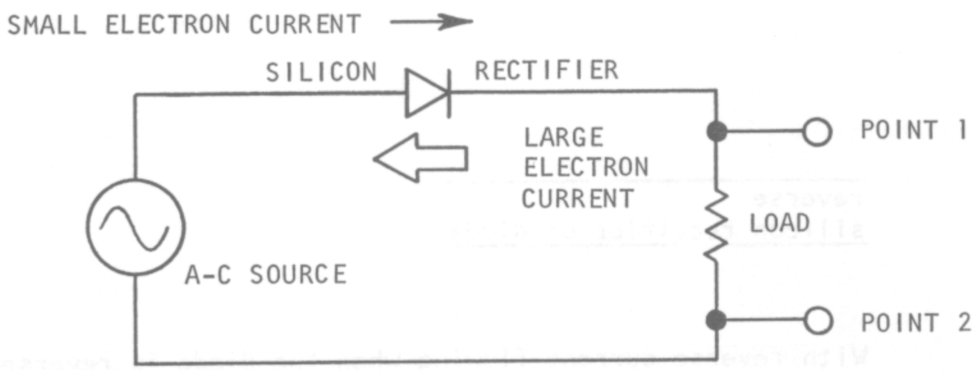
7.5 The diode in the diagram can allow a large electron current to flow



(limited by the load resistance) when forward biased, and only a small reverse current when reverse biased. The voltage across the load will be pulsating d-c and point 1 will be ______________ with respect to point 2.
(negative, positive)

current

7.6 Reversing the connections on the diode, as shown, results in point 1 being ________________ with respect to point 2.



negative

7.7 The silicon rectifier allows easy conduction when forward biased, and very little conduction when reverse biased. Placed in series with an a-c source, it will deliver ____________ ____________ to the load.

positive

7.8 The polarity of the pulsating d-c can be changed by reversing the connections on the ________________.

pulsating d-c

7.9** The silicon rectifier will convert a-c to ______________ ______________. The a-c will alternately ______________ bias and ____________ bias the diode. Reversing the connections on the diode reverses the ___________ of the pulsating d-c.

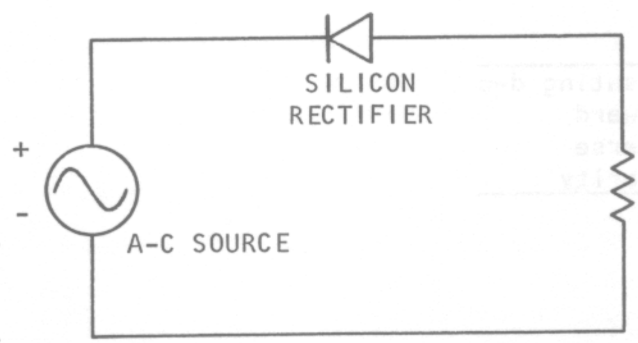
diode

7.10 END OF SET

pulsating d-c
forward
reverse
polarity

8 The maximum reverse voltage at a given temperature than can be applied to a diode before breakdown occurs is termed the __________ __________ __________ rating and this should be greater than the maximum expected __________ value of applied a-c voltage. Maximum reverse current is also measured at this point, and the two values may be used to determine the reverse __________ of the diode.

8.1 With the instantaneous polarity of the a-c source shown, most of the applied voltage is across the diode. If the peak value of the applied a-c voltage is too high, the diode will __________ __________.



peak inverse voltage
peak
resistance

8.2 The maximum peak reverse or inverse voltage that can be applied before breakdown occurs is termed peak inverse voltage. The peak value of applied a-c voltage should be __________ (more, less) than this value.

break down (avalanche)

8.3 Maximum reverse current is measured at the peak inverse voltage point and is the maximum current at a given temperature that will flow with ________ inverse voltage applied.

less

8.4 The reverse resistance of the diode can be found by dividing peak inverse voltage by maximum ____________ ____________.

peak

8.5 Given a peak inverse voltage rating of 500 volts and a maximum reverse current of 10 μamps (both given at 25 degrees centigrade), the reverse resistance of the diode is __________ ohms.

reverse current

8.6 The same diode as stated in frame 8.5 has a maximum reverse current of 500 μamps at 150 degrees centigrade. Its reverse resistance has decreased to approximately _____________ ohms at this temperature.

50 meg

8.7 The product of maximum reverse current and reverse resistance is equal to the ____________ ______________ ______________ rating of the diode.

1 meg

8.8** The maximum reverse voltage that can be applied to a diode without breakdown occuring is termed the ____________ ______________ ______________ rating and the temperature should be specified. Reverse resistance may be found by dividing the peak inverse voltage rating by the maximum ______________ ______________ rating.

peak inverse voltage

8.9 END OF SET

peak inverse voltage
reverse current

9 The maximum forward voltage drop is the maximum voltage across the ______________ when forward biased at a given forward current and _____________. Maximum forward current is the maximum steady state current that can be passed by the rectifier at a given ___________. The product of forward voltage and current gives the ____________ ____________ and these two values may also be used to calculate forward _____________.

9.1 The forward voltage drop of the diode will vary with both forward current and temperature. The forward voltage drop (at low currents) will ___________________ with a decrease in temperature.
(increase, decrease)

diode
temperature
temperature
power dissipation
resistance

9.2 Since forward voltage drop will vary with ______________ and forward ________________, both must be specified when a maximum value of forward voltage is given.

increase

9.3 The product of maximum forward current and voltage will give the maximum power dissipation of the diode. Dividing forward voltage by forward current gives the forward ______________ of the diode.

temperature
current

9.4 The product of total thermal resistance and forward power dissipation gives the rise in junction temperature due to power dissipation. Adding this rise in junction temperature to ambient temperature gives the junction temperature.

resistance

9.5 The product of power dissipation and the thermal resistance of the diode plus ambient temperature must be less than the maximum operating ______________ of the diode.

no answer needed

9.6 If the product of total thermal resistance (Θ_{JA}) and power dissipation (P_d) added to the ambient temperature is higher than the maximum operating temperature of the diode, the diode will be ______________________.

temperature

9.7 "Average half-wave rectified current" is used to designate maximum steady state current. Peak one cycle surge current indicates a non-repetitive peak of current. Maximum peak one cycle surge current will have a ______ value than average half-wave rectified current.
(higher, lower)

damaged (destroyed)

9.8 The maximum allowable operating temperature of the junction and the ambient temperature set a limit on the maximum power dissipation (current and voltage) of a diode, therefore, maximum values of current and voltage should be given at a value of ______________ temperature.

higher

9.9** The product of forward voltage and current gives the __________ dissipation. Maximum forward voltage drop is the maximum voltage across the diode at a given forward __________ and temperature. Average half-wave rectified current is the maximum __________ __________ forward current that can be passed through the diode at a given temperature. Forward voltage divided by __________ __________ gives the forward resistance.

ambient

9.10 END OF SET

power
current
steady state (d-c)
forward current

10 Power dissipation in silicon rectifiers as in all diode devices, is limited by maximum allowable ______________ temperature, ______________ temperature, and total ______________ ______________ for both the forward and reverse biased conditions. Attaching the diode thermally to an external heat sink increases power handling for a given diode and

______________ ____________________.

10.1 The difference between the ambient temperature and the maximum allowable temperature of the junction gives the allowable rise in junction temperature due to ______________ dissipation.

junction
ambient (surrounding air)
thermal resistance
ambient temperature

10.2 The product of forward current and voltage must not cause the junction temperature to go above maximum diode operating temperature. This is also true of the ______________ voltage and current product.

power

10.3 The maximum power dissipation of a forward biased and a reverse biased diode is limited by ____________________ factors.
(the same, different)

reverse

10.4 A diode operating in avalanche breakdown has its power dissipation limited by the same factors as a forward biased diode. A given diode can dissipate ________ (more, less) power at a lower ambient temperature.

the same

10.5 Heat sinking a diode reduces its total thermal resistance, junction to ambient, and allows more power dissipation for a given diode and ________ ________.

more

10.6 Heat sinking serves ________ (the same, a different) purpose when the diode is operated in a reverse biased mode as/than when it is operated in the forward biased mode.

ambient temperature

10.7** Total ________ ________, ambient temperature, and maximum allowable ________ temperature limits power dissipation in all semiconductor diodes whether they are ________ or ________ biased. Heat sinking increases possible power dissipation for a given diode and ________ ________.

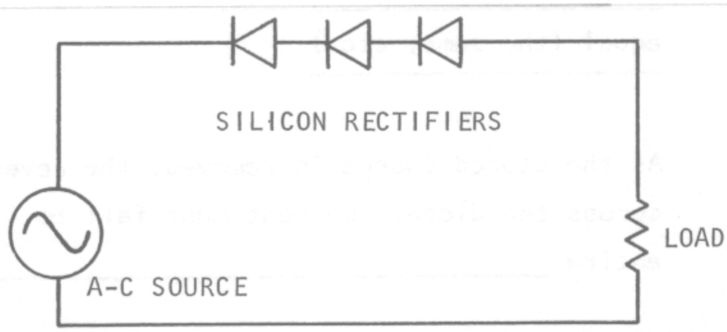
the same

10.8 END OF SET

thermal resistance
junction
forward
reverse
ambient temperature

11 A higher peak inverse voltage rating may be obtained by stacking rectifiers in series. For proper operation, the series rectifiers must have near equal reverse __________ and __________ times.

11.1 Stacking three silicon rectifiers with peak inverse voltage ratings of 500 volts in series should result in a combined peak inverse voltage rating of __________ volts.



resistances
storage

11.2 If the three stacked rectifiers have equal reverse resistances, the applied reverse voltage will divide equally across the three. If the reverse resistances are not equal, the largest reverse resistance will have the greater reverse voltage drop.

1500

11.3 The reverse voltage across the series diodes will be proportional to the reverse resistance of the diodes. If the reverse resistances are not ____________________, one of the diodes may have too much reverse voltage across it and enter a breakdown condition (assuming the applied voltage is greater than the diodes breakdown voltage).

no answer needed

11.4 When a diode is changed from a forward biased condition (conducting) to a reverse biased condition, the stored charge about the junction must be removed before the current can decrease to its normal low value.

equal (the same, etc.)

11.5 As the stored charge is removed, the reverse voltage starts appearing across the diode. Current must fall to its minimum value before the entire ____________________ ____________________ is across the diode.

no answer needed

11.6 If series rectifiers have different stored charges, it will take different times to remove the stored charge when reverse voltage is applied to the conducting diodes. One diode will attempt to become essentially ____________-conducting before the others.

reverse voltage

11.7 When one series rectifier loses its stored charge before the others, nearly the entire applied ______________ ________________ will appear across the faster diode.

non

11.8 With unequal stored charges in series rectifiers, the diode with the smallest stored charge can be harmed since it will have the full peak inverse voltage across it until the ___________ ____________ is removed from the other series diodes.

inverse voltage
or
reverse voltage

11.9** When diodes are placed in series to increase the peak inverse voltage rating, they should be checked for similar ______________ charges and ___________ resistances.

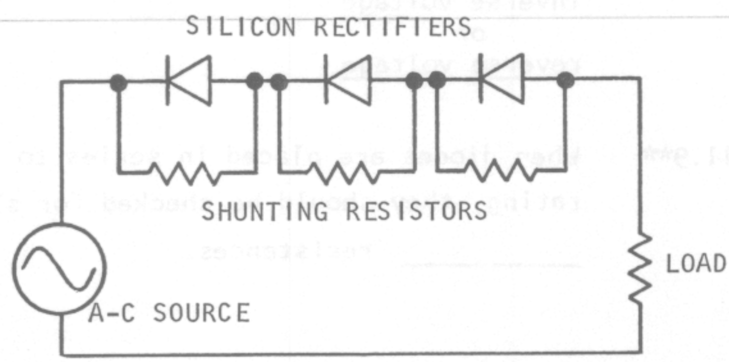
stored charge

11.10 END OF SET

stored
reverse

12 The effects of different reverse resistances in series rectifiers can be reduced by shunting ______________. The optimum value is approximately one half of the ____________ ____________ of the diode.

12.1 Shunting all of the stacked series diodes with resistors will reduce the effects of the differences in reverse resistances of the diodes. Care should be taken that the ____________ ____________ have equal values.



resistors
reverse resistance

12.2 The shunting resistors should be high enough in value to limit reverse current, but low enough in value to aid in distributing the applied ____________ ____________ equally among the diodes.

shunting resistors

12.3 The reverse resistance of the diode can be found by dividing peak inverse voltage by maximum reverse ________________.

inverse voltage
or
reverse voltage

12.4 Typical values of shunting resistors are one half the reverse resistance of the individual diodes. This is small enough to aid in distribution of the applied reverse voltage while large enough to limit ____________ ______________.

current

12.5** Shunting resistors reduce the possibility of breakdown as a result of unequal reverse ________________ in series stacked rectifiers. The optimum value of shunting resistors is approximately one ____________ of the ____________ ____________ of the diode.

reverse current

12.6 END OF SET

resistances
half
reverse resistance

13 Unequal storage times in series stacked silicon rectifiers can be compensated by use of shunting ________________. Optimum values can be found by the formula $\_\_\_ = \frac{t_{s(total)}}{R_L}$ where R_L is the total series ________________ and $t_{s(total)}$ is the sum of the diode ________________ times.

13.1 Shunting the individual series stacked diodes with capacitors slows the response of the diodes, but minimizes the possibility of reverse breakdown as a result of different ________________ times in the individual diodes.

capacitors
C
resistance
storage

13.2 Shunt capacitors slow the fall time of the reverse current when the diode is switched from forward conduction to a reverse biased condition, and the diode will take ____________ (more, less) time to change from a low to a high resistance.

storage

13.3 With capacitors shunting the individual diodes and slowing their transition from conducting to non-conducting, there is less chance of a damaging reverse ________________ appearing across one diode in a series stack.

more

13.4 For optimum performance, the time constant of the shunting capacitors and the series resistance in the circuit should be equal to the total storage time of the diodes or $C\ R_L = t_{s(total)}$, where C is the shunting capacitor, R_L is the series resistance in the circuit, and t_s is the sum of the ______________ ____________ of all the diodes.

voltage

13.5 Transposing the formula $C\ R_L = t_{s(total)}$, $C = \frac{t_{s(total)}}{R_L}$, the value of the shunting capacitor is equal to the total storage time divided by the series ______________________.

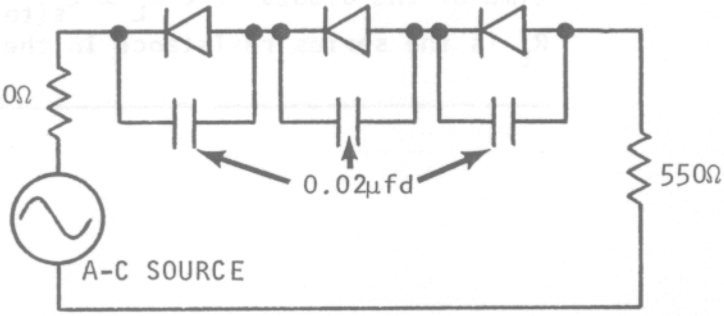
storage times

13.6 Using three diodes in a series stack whose average storage time is 2 μseconds and a series resistance in the circuit of 600Ω, the optimum value of shunting capacitor is ______________________.

$$C = \frac{t_{s(total)}}{R_L} = \frac{6 \times 10^{-6}}{600\Omega} = ?$$

resistance

13.7 If we assume that the capacitors shown have been properly selected to protect the diodes, we might approximate the average storage time of the diodes by transposing the formula:



$$C = \frac{t_{s(total)}}{R_L}$$

$$t_{s(total)} = C\ R_L$$

$$t_{s(total)} = 0.02 \times 10^{-6}\ 600$$

$$t_{s(average)} = \frac{t_{s(total)}}{(\#\ of\ diodes)} = \frac{0.02 \times 10^{-6}\ 600}{3} = \underline{\quad ? \quad}$$

0.01 μfd

13.8** Shunting ____________________ reduce the effects of different storage times in series stacked rectifiers. The optimum value for compensation may be found using the formula

$$\underline{\quad\quad} = \frac{t_{s(total)}}{R_L}$$

where $t_{s(total)}$ equals total ________________ time, and R_L equals total series __________________________.

4 μseconds

13.9 END OF SET

capacitors
C
storage
resistance

14 High voltage silicon rectifier stacks that do not need compensating capacitors and resistors are made with all ________________ cut from the same ______________. This minimizes the problems encountered when dealing with applied ________________ voltages.

14.1 Diodes carefully made from the same crystal will have similar forward and reverse characteristics.

diodes (junctions)
crystal (piece of silicon)
reverse

14.2 With similar forward and reverse characteristics, compensating _________ and/or _____________ are not normally necessary when the diodes are stacked in series to increase the peak inverse voltage rating.

no answer needed

14.3** High voltage rectifier stacks are made with diodes from the same _____________ to minimize the need for compensating ________________ and/or ______________.

resistors
capacitors

14.4 END OF SET

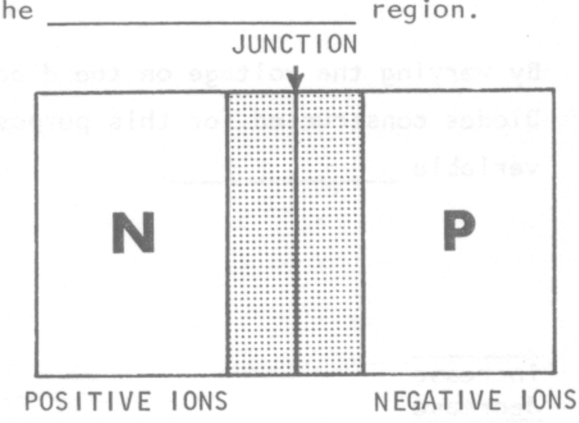
crystal
resistors
capacitors

15 A junction at equilibrium has a ________________ region about the junction and the junction appears as a charged ________________ which may be varied by applying forward or reverse bias voltage. Diodes which are constructed to use this characteristic in circuitry are referred to as ____________ variable ____________.

15.1 When a junction is formed, recombination occurs until a state of equilibrium or balance is reached and a ________________ difference exists across the junction.

depletion
capacitance, capacitor, etc.
voltage
capacitors

15.2 The formation of ions in the two sides of the junction during initial recombination results in an area around the junction that is depleted of carriers and referred to as the ________________ region.



potential, voltage, etc.

15.3 The two ends of the diode separated by the depletion region serve as a

__________________.

---

depletion

15.4 Forward bias forces carriers into the depletion region which, in effect, moves the plates of the capacitor closer together, __________________ (increasing, decreasing) capacitance.

---

capacitor

15.5 Reverse bias widens the depletion region by moving carriers farther from the junction, decreasing capacitance. An a-c voltage applied to a diode will alternately ______________ and ______________ the capacitance.

---

increasing

15.6 By varying the voltage on the diode, the capacitance can be varied. Diodes constructed for this purpose are referred to as ______________ variable ______________.

---

increase
decrease

15.7 Voltage variable capacitors are simply diodes constructed with a predictable ________________ versus voltage characteristic at a given temperature.

voltage
capacitors

15.8 Figure 15A shows a voltage versus current and capacitance chart for a diode. The diode will have the greatest change in capacitance for a change in voltage in the ________________ biased region.

capacitance

15.9 In figure 15A, the capacity falls to minimum when point 1 is reached, since the sharp increase in current, effectively ________________ out the capacitor.

forward

15.10 Figure 15B shows a test set-up to measure capacitance of a junction. The dashed line indicating ________________ in figure 15A can be obtained using this set-up.

shorts

15.11** A voltage variable capacitor is a diode constructed to have predictable ________________ versus capacity characteristics. The capacity is varied by application of _________________ or ___________________ bias. The capacitance is made up of the two ends of the diode separated by the ________________ region.

capacitance

15.12 END OF SET

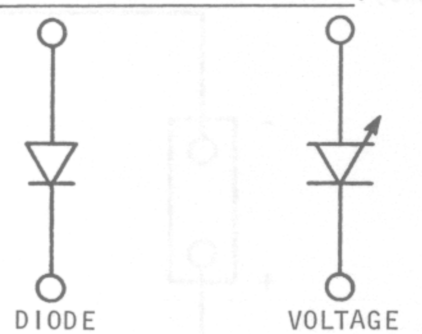
voltage
forward
reverse
depletion

16 ____________________ is the symbol for a voltage variable capacitor. The capacitance is controlled and varied by the applied ________________.

16.1 A voltage variable capacitor is a semiconductor diode designed to serve as a variable capacitor. In the diode symbol shown, A is the __________ and B is the ______________.

voltage

16.2 The diode symbol is modified to indicate a voltage variable capacitor. The capacitor symbol is added to the diode symbol as shown. The added arrow indicates that it is ______________________.

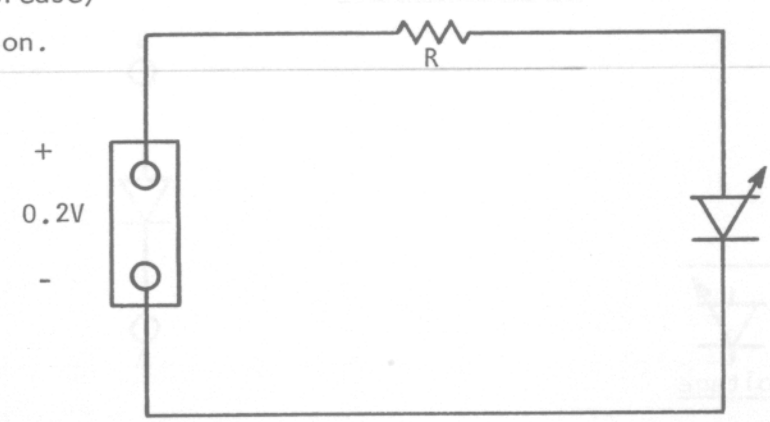


cathode
anode

16.3 In the voltage variable capacitor symbol shown, A is the ______________, and B is the anode.

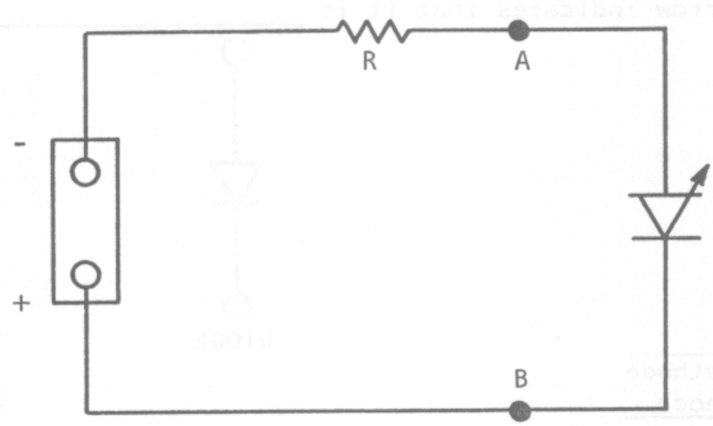
variable

16.4 The polarity of bias shown will ______________ bias the capacitor and ______________ the capacitance of the diode with respect to its
(increase, decrease)
static condition.

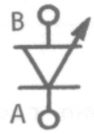


cathode

16.5 To reduce the capacity of the diode shown, point A must become ______________ negative.
(more, less)



forward
increase

16.6**  is the symbol for a ________ ________ ________.

A indicates the ______________, and B indicates the ______________.

The capacitance is varied by changing the applied ______________.

more

16.7 END OF SET

voltage variable capacitor
cathode
anode
voltage

17 A diode designed to operate in the reverse breakdown region with a near constant voltage drop is termed a ________________ diode. The name is misleading, as many of these diodes operate in ______________ breakdown. Close control of doping by the ___________________ process allows the fabrication of diodes with reverse breakdown voltages from a few volts to several hundred volts.

17.1 By controlling the amount of doping impurities added and the geometry of the junction while using silicon as the intrinsic material, zener diodes can be constructed that will break down at a wide variety of ____________ voltages.

zener
avalanche
diffusion

17.2 The greater the amount of doping impurities, the ______________ (higher, lower) the reverse breakdown voltage.

reverse

17.3 Doping by diffusion allows close control of the doping levels and the reverse __________________ voltage of a zener diode.

lower

17.4 Zener diodes designed to break down below 6 volts are probably doped heavy enough to enhance tunneling.

breakdown

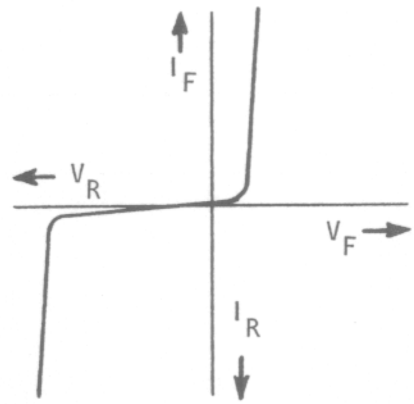
17.5 Tunneling or zener breakdown occurs in very narrow junctions as a result of heavy doping, and breakdown occurs below __________ volts of reverse voltage.

no answer needed

17.6 The name zener diode is often misleading as many zener diodes have breakdown voltages above 6 volts and operate in ______________ breakdown.

6

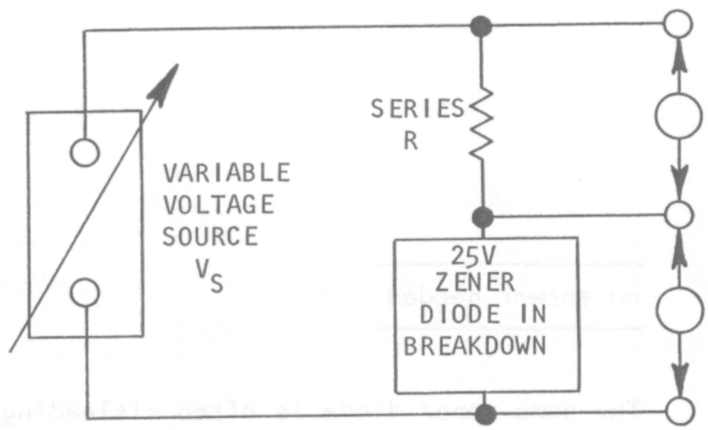
17.7 Once into the breakdown region, the voltage across the ______________ terminals changes very little over a wide range of currents.



avalanche

17.8 With an impedance in series with the zener diode to drop any extra voltage and an applied voltage greater than the reverse breakdown voltage of the diode, the voltage across the ______________ will change very little with changes in applied <u>voltage</u> or <u>current</u> through the diode.

V_S = 50V	V_S = 55V
V_Z = 25V	V_Z = 25V
V_R = 25V	V_R = 30V



diode or junction

17.9 Operated in the breakdown region, the zener diode will maintain a near constant ______________ across its terminals with changes in applied ______________ and ______________.

diode

17.10 Zener diode voltages from a few volts to several hundred volts have been obtained by controlling the ________________ levels with the diffusion process.

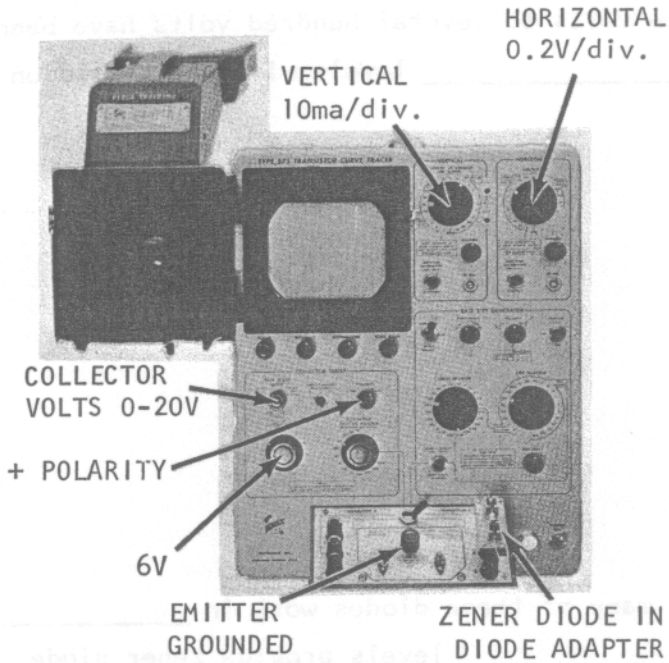
voltage
voltage
current

17.11** Although called a zener diode, many of these diodes work in ____________ breakdown. Controlling the ______________ levels provide zener diode voltages from a few volts to several hundred volts. Operated in break-down, the voltage across the diode changes very little with changes in applied _____________________ and current.

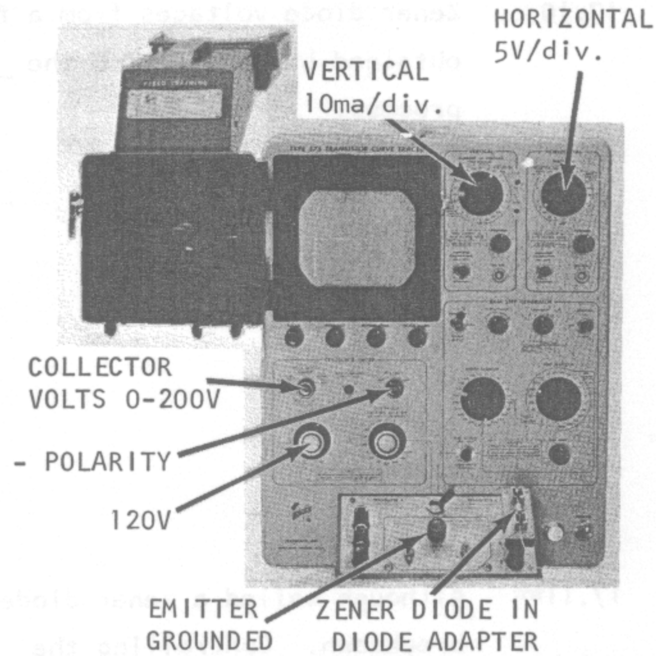
doping or impurity

17.12 END OF SET

avalanche
doping
voltage

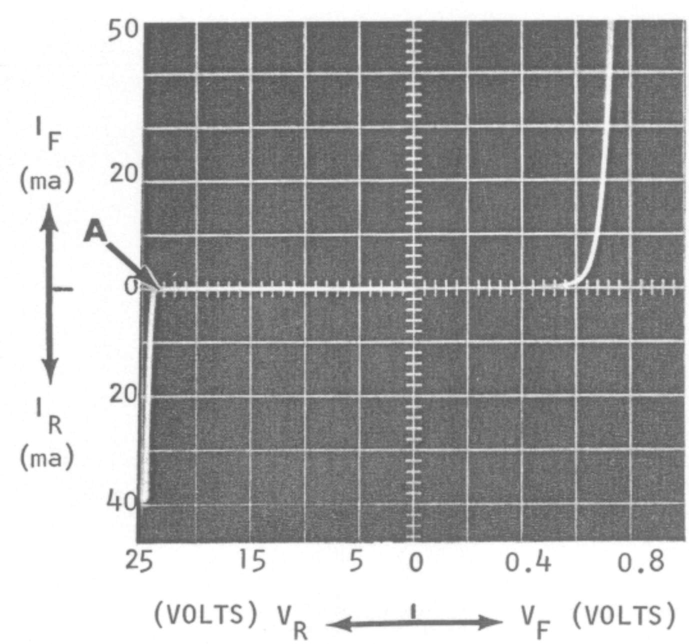


FORWARD CHARACTERISTIC



REVERSE CHARACTERISTIC

TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH DIODE ADAPTER AND TYPE C-12 OSCILLOSCOPE CAMERA



I_F = FORWARD CURRENT

I_R = REVERSE CURRENT

V_F = FORWARD VOLTAGE

V_R = REVERSE VOLTAGE

COMPOSITE: DOUBLE EXPOSURE SHOWING BOTH FORWARD AND REVERSE EI CHARACTERISTICS OF A ZENER DIODE

FIGURE 18A

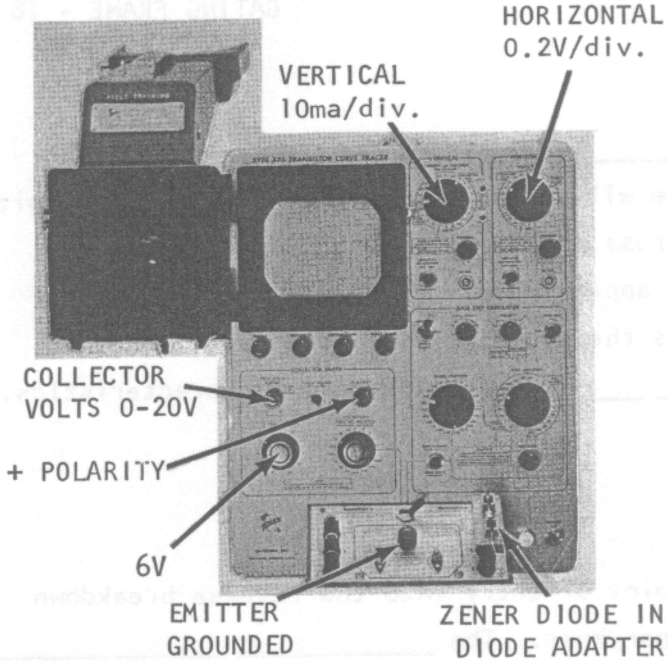
18 Point A in figure 18A is the ______________ ______________ and, with 40 ma of reverse current, there will be approximately ____________ volts of ______________ voltage across the diode. With 20 ma of forward current flowing, there will be approximately ______________ volts of ______________ voltage across the diode. This diode is designed to work in the ____________ ____________ region of its characteristics.

18.1 Point A in figure 18A is the point of entry into the reverse breakdown condition and is termed the zener knee. The ____________ ______________ in figure 18A occurs at approximately 24 volts.

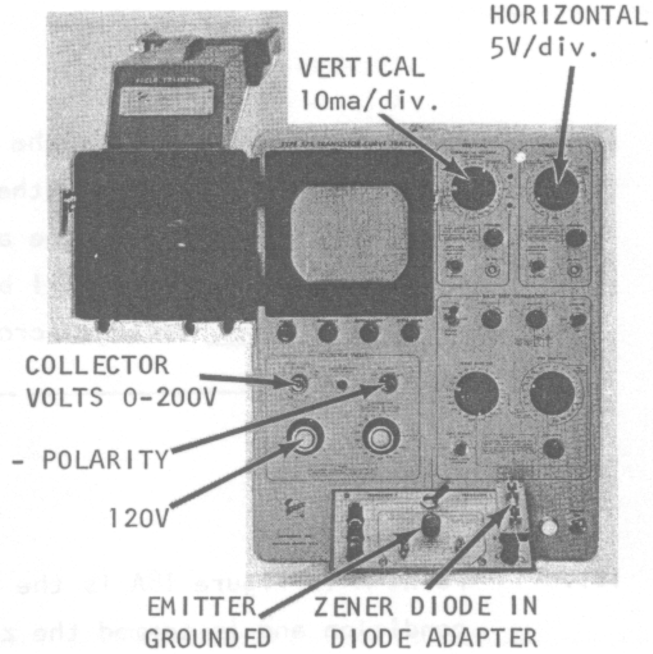
zener knee
25
reverse
0.7
forward
reverse breakdown

18.2 The zener diode is designed to work beyond the zener knee or, in the case of the diode in figure 18A, in ________________ breakdown (breakdown occurs above 6 volts).

zener knee

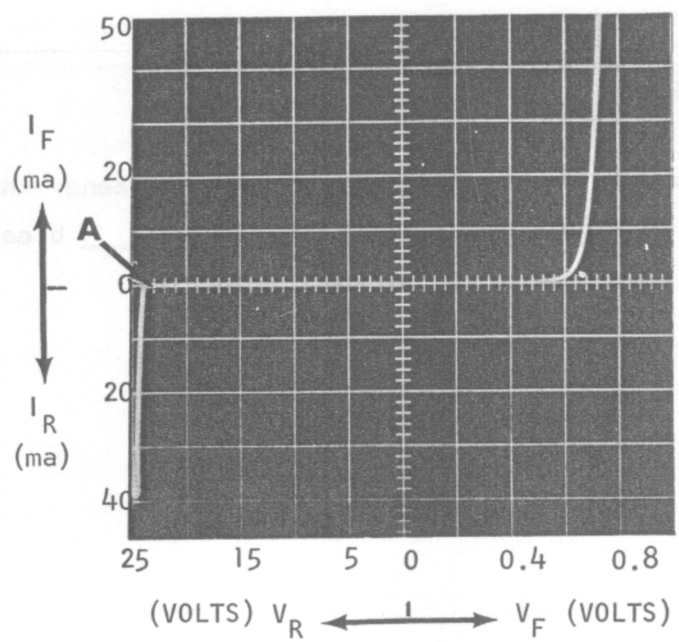


FORWARD CHARACTERISTIC



REVERSE CHARACTERISTIC

TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH DIODE ADAPTER AND TYPE C-12 OSCILLOSCOPE CAMERA



I_F = FORWARD CURRENT

I_R = REVERSE CURRENT

V_F = FORWARD VOLTAGE

V_R = REVERSE VOLTAGE

COMPOSITE: DOUBLE EXPOSURE SHOWING BOTH FORWARD AND REVERSE EI CHARACTERISTICS OF A ZENER DIODE

FIGURE 18A

18.3 The curve tracer in figure 18A is first adjusted for a horizontal sensitivity of 0.2 volts/division, and a vertical sensitivity of 10 ma/division and a plus polarity. The resultant display is the plot of diode

_______________ _______________ versus _______________.
(forward, reverse)

avalanche

18.4 The curve tracer in figure 18A is then adjusted for a horizontal sensitivity of 5 volts/division, and a vertical sensitivity of 10 ma/division and a minus polarity. The resultant display is a plot of reverse _______________ versus _______________.

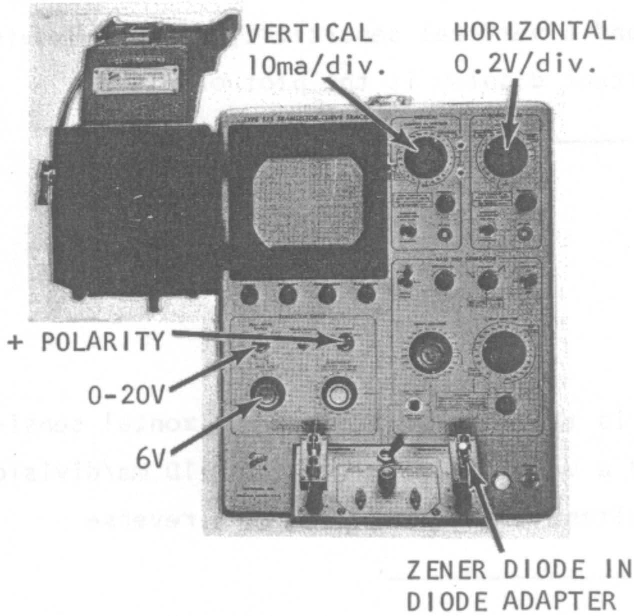
forward
voltage
current

18.5 A photographic exposure is made of both the forward and reverse display, and the resultant curve shows both the forward and reverse characteristics of the zener diode. The exact center of the scale used in figure 18A indicates __________(#) volts and __________(#) current.

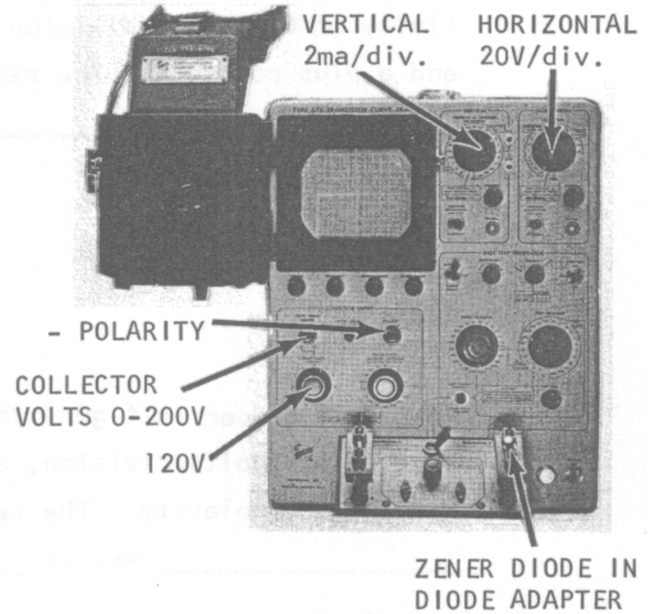
voltage
current

18.6 If it is desired to have 25 volts across the diode in figure 18A, it should be operated near a reverse current of _______________ ma.

0
0

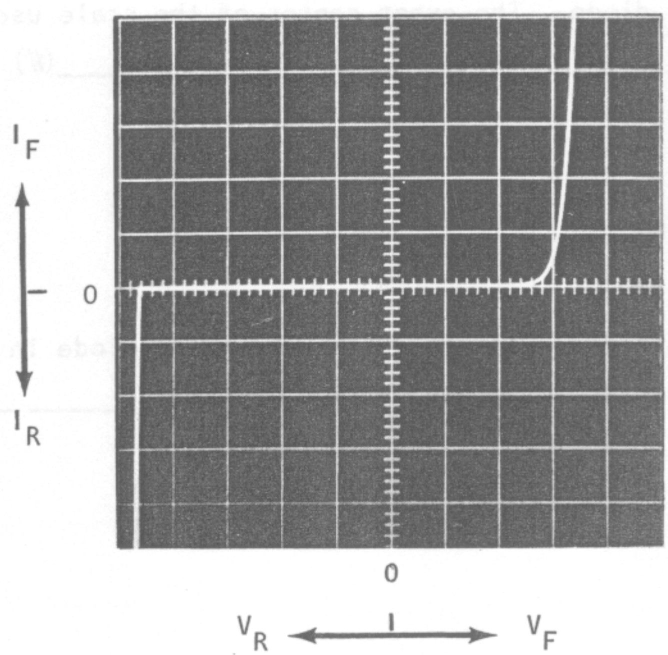


FORWARD CHARACTERISTIC



REVERSE CHARACTERISTIC

TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH DIODE ADAPTER AND TYPE C-12 OSCILLOSCOPE CAMERA.



COMPOSITE

DOUBLE EXPOSURE SHOWING BOTH THE FORWARD AND REVERSE CHARACTERISTIC OF A ZENER DIODE

FIGURE 18B

18.7 Operating with 40 ma of reverse current and 25 volts, the diode will dissipate ____________ watt/s of power.

40

18.8 The center of the scale or graticule used in figure 18B indicates zero ____________________ and zero ______________________.

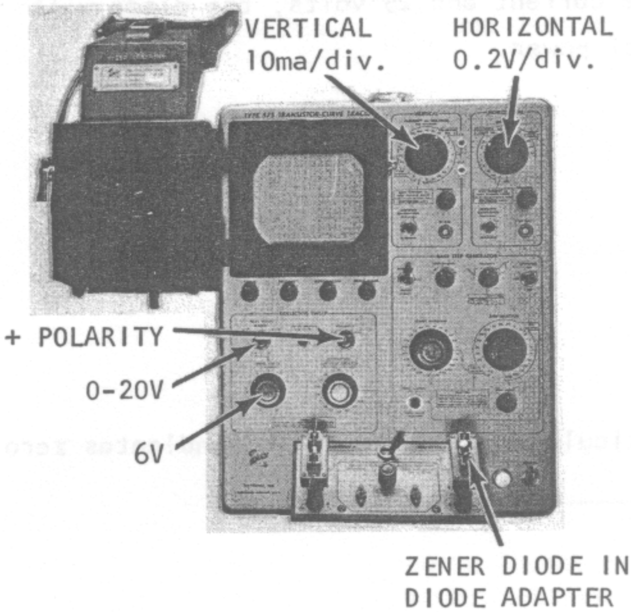
one

18.9 The horizontal scale of reverse voltage (V_R) in figure 18B is 20 volts/major division. The zener knee occurs at approximately 4.6 major divisions from zero or approximately _________ volts of reverse voltage.

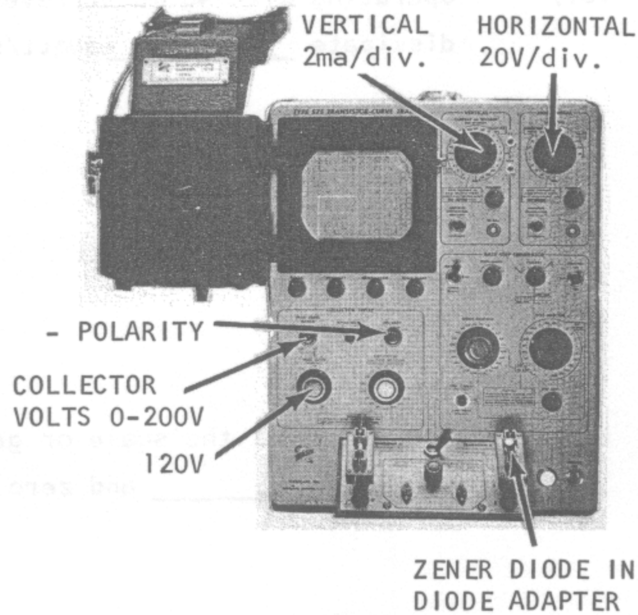
voltage
current

18.10 With forward voltage applied and the diode conducting 50 ma of forward current, the diode in figure 18B will have about _____________ volts across its terminals. (Remember to use the horizontal and vertical sensitivities for the forward characteristic.)

92

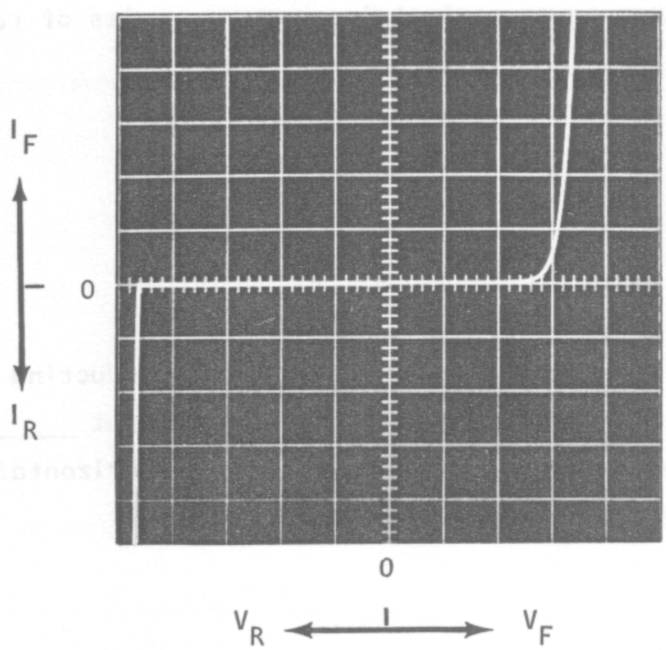


FORWARD CHARACTERISTIC



REVERSE CHARACTERISTIC

TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH DIODE ADAPTER AND TYPE C-12 OSCILLOSCOPE CAMERA.



COMPOSITE

DOUBLE EXPOSURE SHOWING BOTH THE FORWARD AND REVERSE CHARACTERISTIC OF A ZENER DIODE

FIGURE 18B

18.11 With 10 ma of reverse current flowing through the diode in figure 18B, about __________ volts appears across the diode. (Use the horizontal and vertical sensitivities for the reverse characteristics.)

0.7

18.12** Properly biased for normal zener diode operation, the diode in figure 18B will have about __________ volts of ______________ voltage across its terminals.
(forward, reverse)

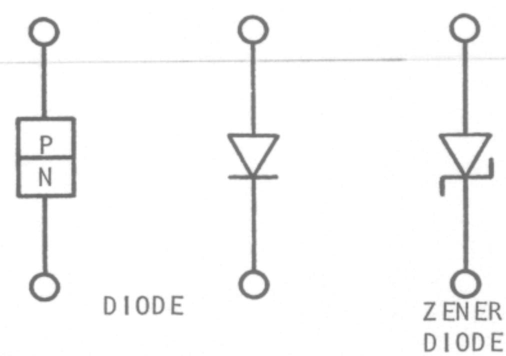
93

18.13 END OF SET

93
reverse

19 ____________________ is the symbol for a zener diode. Operated in breakdown, electron current will flow ______________ (with, against) the arrow in the symbol. Power dissipation is limited by ____________________ (the same, different) considerations as other diodes.

19.1 A Z is added to the conventional diode symbol to indicate a zener diode. The zener diode is normally _________________ (forward, reverse) biased in circuitry.



with

the same

19.2 Rectifier diodes conduct heavily when forward biased and depend on ____________________ (majority, minority) carriers crossing the junction and becoming ____________________ carriers which find imperfections and recombine.

reverse

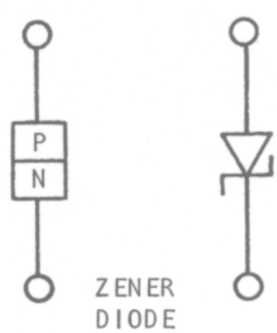
19.3 The zener diode operates in a reverse biased mode and depends on __________________ carriers crossing the junction for current.

majority
minority

19.4 Electrons from the P side of zener diodes are accelerated toward the N side and result in avalanche __________________ beyond the zener knee.

minority

19.5 Electrons will flow from the P side to the N side, or __________________ (with, against) the arrow in the zener diode symbol.

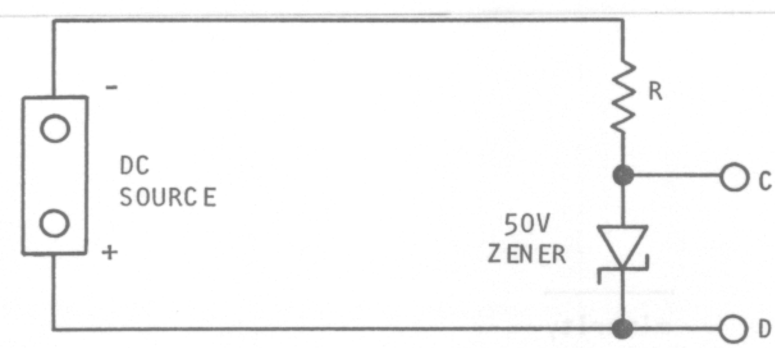


breakdown

19.6 For proper operation, A should be _____ (+, -) with respect to B, and greater than ______________ volts. C will be a _____ (+, -) ____________ volts with respect to D.

with

19.7 Assuming no components were harmed if the terminals of the zener diode were reversed, about ______________ volts would be measured between C and D in the circuit shown if the polarity of the source remained the same.



(-)
50
(-)
50

19.8 The same power dissipation limiting factors apply to the zener diode as other diodes, although it is normally operated in a ________________ biased mode.

0.7

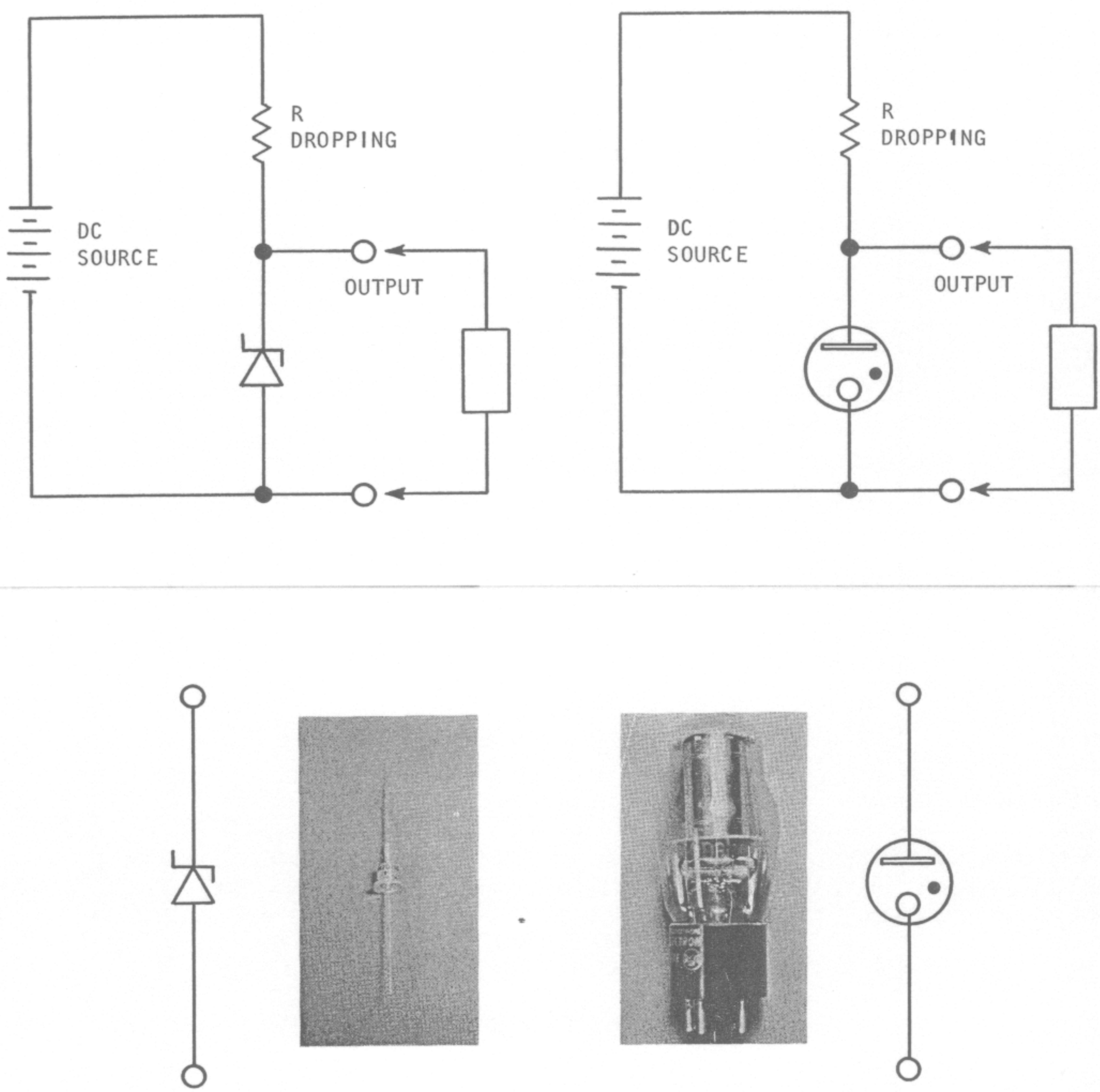


FIGURE 20

19.9**

is the symbol for a ________________ diode. Normal operation has electron current flowing from ____________ to ___________ in the symbol. ____________________ factors limit power dissipation in
(The same, Different)
this diode as/than other diodes.

reverse

19.10 END OF SET

zener
B
A
The same

20 Figure 20 compares the basic zener diode circuit with the familiar gas filled regulator tube or VR tube circuit. The VR tube is limited to a minimum voltage of about ______________ volts, and current levels set by the internal geometry of the tube. The VR tube will have ___________ drift for several minutes when first turned on.

20.1 The basic operations of the VR tube and the zener diode in figure 20 are the same. The applied voltage is ______________ than the breakdown
(higher, lower)
voltage of the zener and the ionization level of the VR tube. The series ________________ drops the added voltage.

70
voltage

20.2 The circuit to be supplied is connected across the output terminals and receives a regulated voltage. If the load current changes, the _________ of a zener diode (or VR tube) will change to compensate.

higher
resistor

20.3 If the voltage of the d-c source in figure 20 changes value, the zener diode (or the VR tube) changes its current, dropping a different voltage across the ________________ while holding output voltage constant.

current

20.4 One advantage of the zener diode over the VR tube is its availability over the entire voltage range from a few volts to several hundred volts. The VR tube is limited to the minimum ionization voltage of the gas used.

resistor

20.5 The minimum ______________ voltage of gas used in VR tubes is about 70 volts. This means that VR tubes must operate at ___________ volts or above.

no answer needed

20.6 The current in a VR tube is limited by the internal size and shape or geometry of the tube. If too much current flows, the tube burns up and, if too little current flows, the gas _________________ and the tube does not function.

ionization
70

20.7 When first turned on, the VR tube gas takes a few minutes to stabilize. During this "warm up" period, the output voltage of the VR tube is not stable, while the zener has no measureable drift when first turned on.

de-ionizes

20.8 The output voltage of the VR tube will ______________ when first turned on, while the zener diode output voltage will not.

no answer needed

20.9** The zener diode and the ________________ tube are similar in operation, but with the zener diode offering a wider variety of _________________, less ____________ ______________ when first turned on and a wider range of currents, while holding ______________ voltage near constant.

drift, vary, etc.

20.10 END OF SET

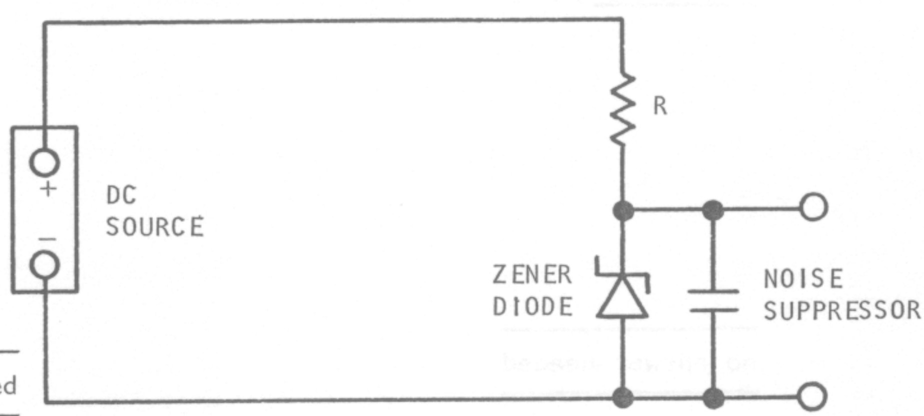
VR (voltage regulator
voltages
output or voltage drift
output or diode

21 The noise levels generated by the gaseous discharge in a VR tube and a zener diode in avalanche are of ________________ (the same, different) magnitude. The noise in a ____________ ____________ can be suppressed by a shunting capacitor, while the same compensation on a ____________ ____________ could cause it to break into relaxation oscillations. Optimum values of capacitors range from ____________ to ____________ μfd.

21.1 The continuous ionization and de-ionization of the gas in a VR tube, and the avalanche effects of the zener diode generate about the same amount of noise.

the same
zener diode
VR tube
0.01
0.1

21.2 A capacitor placed in shunt with the zener diode will reduce the ____________ by a factor of 10 when the capacitor has a value of 0.01 to 0.1μfd.

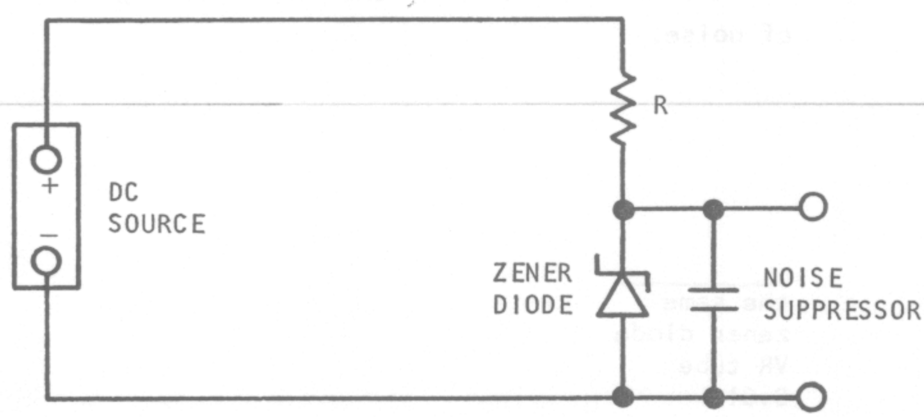


no answer needed

21.3 When placing a capacitor in shunt with a VR tube, the limited ionization current levels of the VR tube cause it to break into relaxation oscillations. Although the zener diode generates about the same amount of noise, it can be compensated with a shunt ________________.

noise

21.4 A 0.01 μfd to 0.1 μfd capacitor in shunt with a zener diode will reduce the noise level by a factor of about 10.



capacitor

21.5 The noise generated in a zener diode can be reduced to about one tenth its magnitude by addition of a shunt capacitor of about _______ μfd to _________ μfd.

no answer needed

21.6** About the same magnitude of noise levels are generated in the zener in ____________________ breakdown and a VR tube when the gas is ____________________. The noise in the ____________ ____________ can be compensated with a shunt capacitor of 0.01 to __________ μfd, while the same compensation on a ____________ ____________ could result in relaxation oscillation occuring.

0.01
0.1

21.7 END OF SET

avalanche
ionized
zener diode
0.1
VR tube

22 A zener diode in avalanche breakdown has a ________________ temperature coefficient of voltage, and a forward biased diode has a __________ temperature coefficient of voltage at low currents. In series, they ________________ compensate each other. Series opposed ____________ diodes tend to temperature compensate each other.

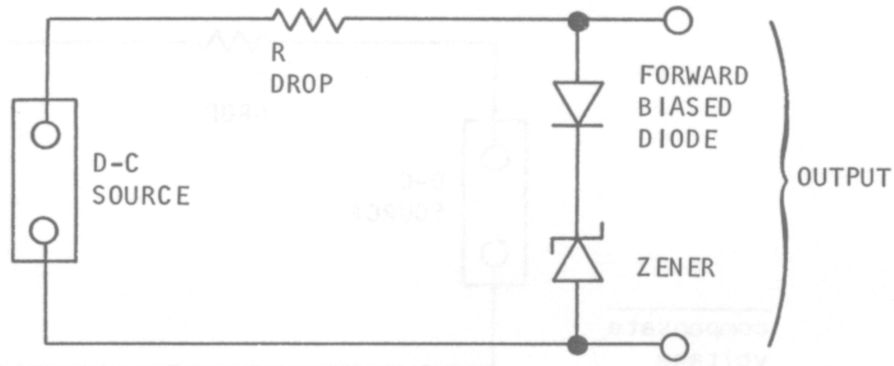
22.1 An increase in temperature results in a decrease in the voltage across a forward biased diode. This is termed a negative temperature coefficient of voltage.

positive
negative
temperature
zener

22.2 A diode in avalanche breakdown has a positive temperature coefficient of voltage, and the voltage across the diode will ________________ (increase, decrease) with an increase in temperature.

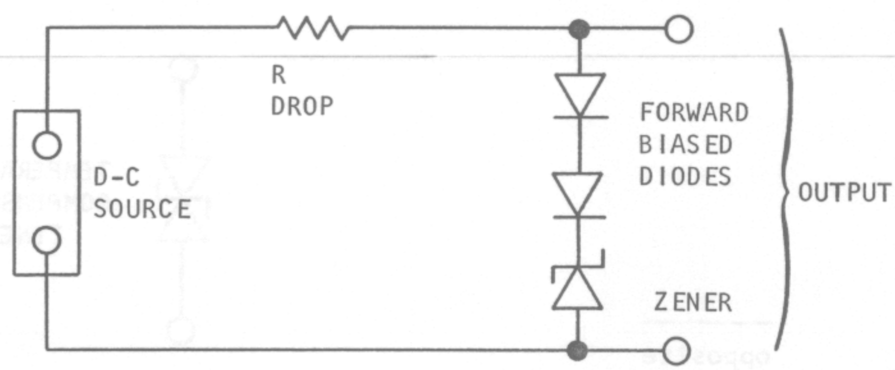
no answer needed

22.3 Placed in series, the decrease in voltage across one will tend to offset the increase in voltage across the other with changes in ______________.



increase

22.4 If one forward biased diode gives insufficient compensation, more may be added in ________________ with the zener diode.

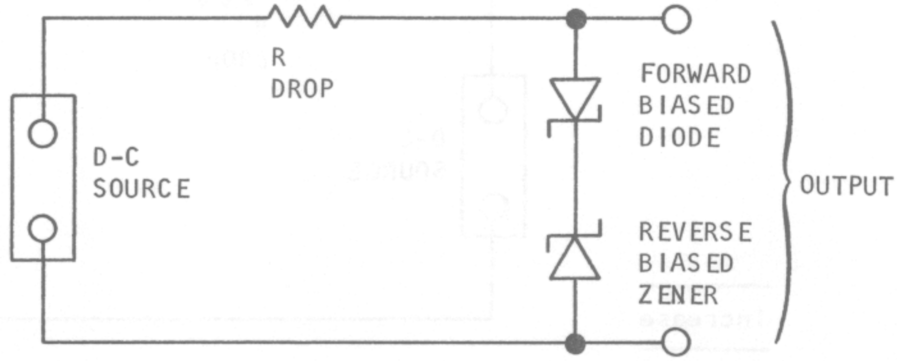


temperature

22.5 Since forward biased diodes and zeners (operating in avalanche breakdown) have opposite temperature coefficients of voltage, connected in series they temperature ________________ each other and maintain a more constant output ______________ with changes in temperature.

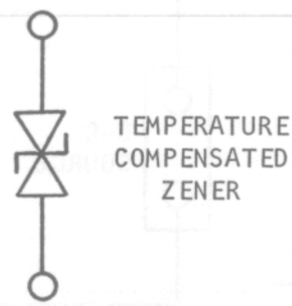
series

22.6 A forward biased zener diode in series with a zener diode operating in avalanche breakdown will have ________________ (the same, opposite) temperature coefficients of voltage.



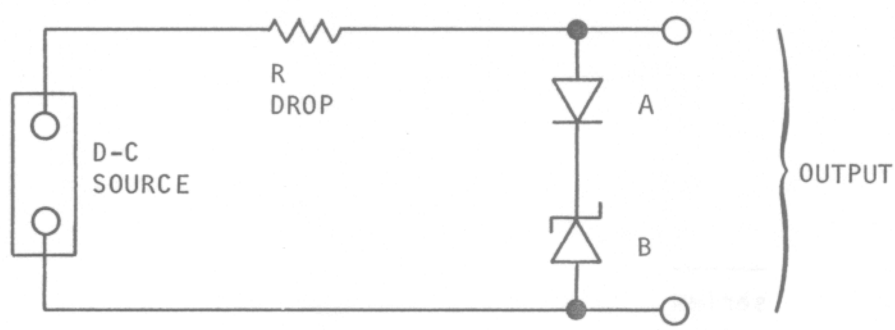
compensate
voltage

22.7 Zeners are available, connected in series opposition in the same encapsulation. This type of zener will tend to ________________ compensate the ________________ across its terminals.



opposite

22.8 Forward biased diodes in series with zener diodes are used for temperature compensation of voltage. An increase in temperature will cause an increase in the voltage across diode ____________, and a decrease in the voltage across diode ________________ in the diagram.



temperature
voltage

22.9** Compensating the positive temperature coefficient of voltage of a ____________ ____________ with the negative temperature coefficient of voltage of a ____________ ____________ diode results in very little change in voltage across both devices for a change in ____________. Zener diodes connected in series opposition tend to temperature compensate the ____________ across the two devices.

B
A

22.10 END OF SET

zener diode
forward biased
temperature
voltage

COURTESY: MOTOROLA SEMICONDUCTOR PRODUCTS, INC., PHOENIX, ARIZONA

ELECTRICAL CHARACTERISTICS (@ 30°C Case unless otherwise specified)

JEDEC TYPE NUMBER	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} ohms	Z_{ZK} @ I_{ZK} ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage (V_F) Volts @I_F = 2 Amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2970	10M6.8Z	6.8	370	1.2	500	1.0	1,320	1.5	.040
1N2971	10M7.5Z	7.5	335	1.3	250	1.0	1,180	1.5	.045
1N2972	10M8.2Z	8.2	305	1.5	250	1.0	1,040	1.5	.048
1N2973	10M9.1Z	9.1	275	2.0	250	1.0	960	1.5	.051
1N2974	10M10Z	10	250	3	250	1.0	860	1.5	.055
1N2975	10M11Z	11	230	3	250	1.0	780	1.5	.060
1N2976	10M12Z	12	210	3	250	1.0	720	1.5	.065
1N2977	10M13Z	13	190	3	250	1.0	660	1.5	.065
1N2979	10M15Z	15	170	3	250	1.0	560	1.5	.070
1N2980	10M16Z	16	155	4	250	1.0	530	1.5	.070
1N2982	10M18Z	18	140	4	250	1.0	460	1.5	.075
1N2984	10M20Z	20	125	4	250	1.0	420	1.5	.075
1N2985	10M22Z	22	115	5	250	1.0	380	1.5	.080
1N2986	10M24Z	24	105	5	250	1.0	350	1.5	.080
1N2988	10M27Z	27	95	7	250	1.0	300	1.5	.085
1N2989	10M30Z	30	85	8	300	1.0	280	1.5	.085
1N2990	10M33Z	33	75	9	300	1.0	260	1.5	.085
1N2991	10M36Z	36	70	10	300	1.0	230	1.5	.085
1N2992	10M39Z	39	65	11	300	1.0	210	1.5	.085
1N2993	10M43Z	43	60	12	400	1.0	195	1.5	.090
1N2995	10M47Z	47	55	14	400	1.0	175	1.5	.090
1N2997	10M51Z	51	50	15	500	1.0	160	1.5	.090
1N2999	10M56Z	56	45	16	500	1.0	150	1.5	.090
1N3000	10M62Z	62	40	17	600	1.0	130	1.5	.090
1N3001	10M68Z	68	37	18	600	1.0	120	1.5	.090
1N3002	10M75Z	75	33	22	600	1.0	110	1.5	.090
1N3003	10M82Z	82	30	25	700	1.0	100	1.5	.090
1N3004	10M91Z	91	28	35	800	1.0	85	1.5	.090
1N3005	10M100Z	100	25	40	900	1.0	80	1.5	.090
1N3007	10M110Z	110	23	55	1,100	1.0	72	1.5	.095
1N3008	10M120Z	120	20	75	1,200	1.0	67	1.5	.095
1N3009	10M130Z	130	19	100	1,300	1.0	62	1.5	.095
1N3011	10M150Z	150	17	175	1,500	1.0	54	1.5	.095
1N3012	10M160Z	160	16	200	1,600	1.0	50	1.5	.095
1N3014	10M180Z	180	14	260	1,850	1.0	45	1.5	.095
1N3015	10M200Z	200	12	300	2,000	1.0	40	1.5	.100

JEDEC TYPE NO.	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage V_F @ 10 amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2804	50M6.8Z	6.8	1850	0.2	70	5	6,600	1.5	.040
1N2805	50M7.5Z	7.5	1700	0.3	70	5	5,900	1.5	.045
1N2806	50M8.2Z	8.2	1500	0.4	70	5	5,200	1.5	.048
1N2807	50M9.1Z	9.1	1370	0.5	70	5	4,800	1.5	.051
1N2808	50M10Z	10	1200	0.6	80	5	4,300	1.5	.055
1N2809	50M11Z	11	1100	0.8	80	5	3,900	1.5	.060
1N2810	50M12Z	12	1000	1.0	80	5	3,600	1.5	.065
1N2811	50M13Z	13	960	1.1	80	5	3,300	1.5	.065
1N2813	50M15Z	15	830	1.4	80	5	2,800	1.5	.070
1N2814	50M16Z	16	780	1.6	80	5	2,650	1.5	.070
1N2816	50M18Z	18	700	2.0	80	5	2,300	1.5	.075
1N2818	50M20Z	20	630	2.4	80	5	2,100	1.5	.075
1N2819	50M22Z	22	570	2.5	80	5	1,900	1.5	.080
1N2820	50M24Z	24	520	2.6	80	5	1,750	1.5	.080
1N2822	50M27Z	27	460	2.8	90	5	1,500	1.5	.085
1N2823	50M30Z	30	420	3.0	90	5	1,400	1.5	.085
1N2824	50M33Z	33	380	3.2	90	5	1,300	1.5	.085
1N2825	50M36Z	36	350	3.5	90	5	1,150	1.5	.085
1N2826	50M39Z	39	320	4.0	90	5	1,050	1.5	.090
1N2827	50M43Z	43	290	4.5	90	5	975	1.5	.090
1N2829	50M47Z	47	270	5.0	100	5	880	1.5	.090
1N2831	50M51Z	51	245	5.2	100	5	810	1.5	.090
1N2833	50M62Z	62	200	7	120	5	660	1.5	.090
1N2834	50M68Z	68	180	8	140	5	600	1.5	.090
1N2835	50M75Z	75	170	9	150	5	540	1.5	.090
1N2836	50M82Z	82	150	11	160	5	490	1.5	.090
1N2837	50M91Z	91	140	15	180	5	420	1.5	.090
1N2838	50M100Z	100	120	20	200	5	400	1.5	.090
1N2840	50M110Z	110	110	30	220	5	365	1.5	.095
1N2841	50M120Z	120	100	40	240	5	335	1.5	.095
1N2842	50M130Z	130	95	50	275	5	310	1.5	.095
1N2843	50M150Z	150	85	75	400	5	270	1.5	.095
1N2844	50M160Z	160	80	80	450	5	250	1.5	.095
1N2845	50M180Z	180	68	90	525	5	220	1.5	.095
1N2846	50M200Z	200	65	100	600	5	200	1.5	.100

FIGURE 23

23 The 10 watt, 47 volt zener diode listed in figure 23 will offer ________ ohms impedance to an a-c signal when operated at the nominal zener voltage, and has a ____________%/°C zener voltage temperature coefficient.

23.1 The number preceeding the M in the Motorola type number indicates the wattage rating, while the number following the M indicates the nominal zener voltage.

14
0.09

23.2 The 1N2__________ is a 10 watt, 47 volt zener diode, and the nominal zener voltage was measured at a test current of __________ma.

no answer needed

23.3 The zener voltage of a given zener diode will vary with both zener current and __________________.

995
55

COURTESY: MOTOROLA SEMICONDUCTOR PRODUCTS, INC., PHOENIX, ARIZONA

ELECTRICAL CHARACTERISTICS (@ 30°C Case unless otherwise specified)

JEDEC TYPE NUMBER	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} ohms	Z_{ZK} @ I_{ZK} ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage (V_F) Volts @I_F = 2 Amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2970	10M6.8Z	6.8	370	1.2	500	1.0	1,320	1.5	.040
1N2971	10M7.5Z	7.5	335	1.3	250	1.0	1,180	1.5	.045
1N2972	10M8.2Z	8.2	305	1.5	250	1.0	1,040	1.5	.048
1N2973	10M9.1Z	9.1	275	2.0	250	1.0	960	1.5	.051
1N2974	10M10Z	10	250	3	250	1.0	860	1.5	.055
1N2975	10M11Z	11	230	3	250	1.0	780	1.5	.060
1N2976	10M12Z	12	210	3	250	1.0	720	1.5	.065
1N2977	10M13Z	13	190	3	250	1.0	660	1.5	.065
1N2979	10M15Z	15	170	3	250	1.0	560	1.5	.070
1N2980	10M16Z	16	155	4	250	1.0	530	1.5	.070
1N2982	10M18Z	18	140	4	250	1.0	460	1.5	.075
1N2984	10M20Z	20	125	4	250	1.0	420	1.5	.075
1N2985	10M22Z	22	115	5	250	1.0	380	1.5	.080
1N2986	10M24Z	24	105	5	250	1.0	350	1.5	.080
1N2988	10M27Z	27	95	7	250	1.0	300	1.5	.085
1N2989	10M30Z	30	85	8	300	1.0	280	1.5	.085
1N2990	10M33Z	33	75	9	300	1.0	260	1.5	.085
1N2991	10M36Z	36	70	10	300	1.0	230	1.5	.085
1N2992	10M39Z	39	65	11	300	1.0	210	1.5	.085
1N2993	10M43Z	43	60	12	400	1.0	195	1.5	.090
1N2995	10M47Z	47	55	14	400	1.0	175	1.5	.090
1N2997	10M51Z	51	50	15	500	1.0	160	1.5	.090
1N2999	10M56Z	56	45	16	500	1.0	150	1.5	.090
1N3000	10M62Z	62	40	17	600	1.0	130	1.5	.090
1N3001	10M68Z	68	37	18	600	1.0	120	1.5	.090
1N3002	10M75Z	75	33	22	600	1.0	110	1.5	.090
1N3003	10M82Z	82	30	25	700	1.0	100	1.5	.090
1N3004	10M91Z	91	28	35	800	1.0	85	1.5	.090
1N3005	10M100Z	100	25	40	900	1.0	80	1.5	.090
1N3007	10M110Z	110	23	55	1,100	1.0	72	1.5	.095
1N3008	10M120Z	120	20	75	1,200	1.0	67	1.5	.095
1N3009	10M130Z	130	19	100	1,300	1.0	62	1.5	.095
1N3011	10M150Z	150	17	175	1,500	1.0	54	1.5	.095
1N3012	10M160Z	160	16	200	1,600	1.0	50	1.5	.095
1N3014	10M180Z	180	14	260	1,850	1.0	45	1.5	.095
1N3015	10M200Z	200	12	300	2,000	1.0	40	1.5	.100

JEDEC TYPE NO.	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage V_F @ 10 amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2804	50M6.8Z	6.8	1850	0.2	70	5	6,600	1.5	.040
1N2805	50M7.5Z	7.5	1700	0.3	70	5	5,900	1.5	.045
1N2806	50M8.2Z	8.2	1500	0.4	70	5	5,200	1.5	.048
1N2807	50M9.1Z	9.1	1370	0.5	70	5	4,800	1.5	.051
1N2808	50M10Z	10	1200	0.6	80	5	4,300	1.5	.055
1N2809	50M11Z	11	1100	0.8	80	5	3,900	1.5	.060
1N2810	50M12Z	12	1000	1.0	80	5	3,600	1.5	.065
1N2811	50M13Z	13	960	1.1	80	5	3,300	1.5	.065
1N2813	50M15Z	15	830	1.4	80	5	2,800	1.5	.070
1N2814	50M16Z	16	780	1.6	80	5	2,650	1.5	.070
1N2816	50M18Z	18	700	2.0	80	5	2,300	1.5	.075
1N2818	50M20Z	20	630	2.4	80	5	2,100	1.5	.075
1N2819	50M22Z	22	570	2.5	80	5	1,900	1.5	.080
1N2820	50M24Z	24	520	2.6	80	5	1,750	1.5	.080
1N2822	50M27Z	27	460	2.8	90	5	1,500	1.5	.085
1N2823	50M30Z	30	420	3.0	90	5	1,400	1.5	.085
1N2824	50M33Z	33	380	3.2	90	5	1,300	1.5	.085
1N2825	50M36Z	36	350	3.5	90	5	1,150	1.5	.085
1N2826	50M39Z	39	320	4.0	90	5	1,050	1.5	.090
1N2827	50M43Z	43	290	4.5	90	5	975	1.5	.090
1N2829	50M47Z	47	270	5.0	100	5	880	1.5	.090
1N2831	50M51Z	51	245	5.2	100	5	810	1.5	.090
1N2833	50M62Z	62	200	7	120	5	660	1.5	.090
1N2834	50M68Z	68	180	8	140	5	600	1.5	.090
1N2835	50M75Z	75	170	9	150	5	540	1.5	.090
1N2836	50M82Z	82	150	11	160	5	490	1.5	.090
1N2837	50M91Z	91	140	15	180	5	420	1.5	.090
1N2838	50M100Z	100	120	20	200	5	400	1.5	.090
1N2840	50M110Z	110	110	30	220	5	365	1.5	.095
1N2841	50M120Z	120	100	40	240	5	335	1.5	.095
1N2842	50M130Z	130	95	50	275	5	310	1.5	.095
1N2843	50M150Z	150	85	75	400	5	270	1.5	.095
1N2844	50M160Z	160	80	80	450	5	250	1.5	.095
1N2845	50M180Z	180	68	90	525	5	220	1.5	.095
1N2846	50M200Z	200	65	100	600	5	200	1.5	.100

FIGURE 23

23.4 The temperature coefficient of zener voltage indicates the percentage of variance of nominal zener voltage for each _______________ _______________ of temperature change.

temperature

23.5 A change in temperature of 10°C will cause a change of __________% of the nominal zener voltage of a 1N2995 zener diode.

degree centigrade

23.6 A zener diode operating at its nominal voltage has sufficient 60 cycle voltage applied to cause an a-c current to flow equal to one-tenth of the zener current. The opposition to a-c current is calculated and given the symbol Z_{ZT}. The 1N2995 in figure 23 has a Z_{ZT} of _______________ ohms.

$0.09\%/°C \times 10°C = 0.9\%$

23.7 The a-c impedance is also measured in the same fashion just beyond the zener knee and given the symbol Z_{ZK}. Z_{ZK} of the 1N2995 is _______________ ohms.

COURTESY: MOTOROLA SEMICONDUCTOR PRODUCTS, INC., PHOENIX, ARIZONA

ELECTRICAL CHARACTERISTICS (@ 30°C Case unless otherwise specified)

JEDEC TYPE NUMBER	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} ohms	Z_{ZK} @ I_{ZK} ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage (V_F) Volts @$I_F = 2$ Amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2970	10M6.8Z	6.8	370	1.2	500	1.0	1,320	1.5	.040
1N2971	10M7.5Z	7.5	335	1.3	250	1.0	1,180	1.5	.045
1N2972	10M8.2Z	8.2	305	1.5	250	1.0	1,040	1.5	.048
1N2973	10M9.1Z	9.1	275	2.0	250	1.0	960	1.5	.051
1N2974	10M10Z	10	250	3	250	1.0	860	1.5	.055
1N2975	10M11Z	11	230	3	250	1.0	780	1.5	.060
1N2976	10M12Z	12	210	3	250	1.0	720	1.5	.065
1N2977	10M13Z	13	190	3	250	1.0	660	1.5	.065
1N2979	10M15Z	15	170	3	250	1.0	560	1.5	.070
1N2980	10M16Z	16	155	4	250	1.0	530	1.5	.070
1N2982	10M18Z	18	140	4	250	1.0	460	1.5	.075
1N2984	10M20Z	20	125	4	250	1.0	420	1.5	.075
1N2985	10M22Z	22	115	5	250	1.0	380	1.5	.080
1N2986	10M24Z	24	105	5	250	1.0	350	1.5	.080
1N2988	10M27Z	27	95	7	250	1.0	300	1.5	.085
1N2989	10M30Z	30	85	8	300	1.0	280	1.5	.085
1N2990	10M33Z	33	75	9	300	1.0	260	1.5	.085
1N2991	10M36Z	36	70	10	300	1.0	230	1.5	.085
1N2992	10M39Z	39	65	11	300	1.0	210	1.5	.085
1N2993	10M43Z	43	60	12	400	1.0	195	1.5	.090
1N2995	10M47Z	47	55	14	400	1.0	175	1.5	.090
1N2997	10M51Z	51	50	15	500	1.0	160	1.5	.090
1N2999	10M56Z	56	45	16	500	1.0	150	1.5	.090
1N3000	10M62Z	62	40	17	600	1.0	130	1.5	.090
1N3001	10M68Z	68	37	18	600	1.0	120	1.5	.090
1N3002	10M75Z	75	33	22	600	1.0	110	1.5	.090
1N3003	10M82Z	82	30	25	700	1.0	100	1.5	.090
1N3004	10M91Z	91	28	35	800	1.0	85	1.5	.090
1N3005	10M100Z	100	25	40	900	1.0	80	1.5	.090
1N3007	10M110Z	110	23	55	1,100	1.0	72	1.5	.095
1N3008	10M120Z	120	20	75	1,200	1.0	67	1.5	.095
1N3009	10M130Z	130	19	100	1,300	1.0	62	1.5	.095
1N3011	10M150Z	150	17	175	1,500	1.0	54	1.5	.095
1N3012	10M160Z	160	16	200	1,600	1.0	50	1.5	.095
1N3014	10M180Z	180	14	260	1,850	1.0	45	1.5	.095
1N3015	10M200Z	200	12	300	2,000	1.0	40	1.5	.100

JEDEC TYPE NO.	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage V_F @ 10 amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2804	50M6.8Z	6.8	1850	0.2	70	5	6,600	1.5	.040
1N2805	50M7.5Z	7.5	1700	0.3	70	5	5,900	1.5	.045
1N2806	50M8.2Z	8.2	1500	0.4	70	5	5,200	1.5	.048
1N2807	50M9.1Z	9.1	1370	0.5	70	5	4,800	1.5	.051
1N2808	50M10Z	10	1200	0.6	80	5	4,300	1.5	.055
1N2809	50M11Z	11	1100	0.8	80	5	3,900	1.5	.060
1N2810	50M12Z	12	1000	1.0	80	5	3,600	1.5	.065
1N2811	50M13Z	13	960	1.1	80	5	3,300	1.5	.065
1N2813	50M15Z	15	830	1.4	80	5	2,800	1.5	.070
1N2814	50M16Z	16	780	1.6	80	5	2,650	1.5	.070
1N2816	50M18Z	18	700	2.0	80	5	2,300	1.5	.075
1N2818	50M20Z	20	630	2.4	80	5	2,100	1.5	.075
1N2819	50M22Z	22	570	2.5	80	5	1,900	1.5	.080
1N2820	50M24Z	24	520	2.6	80	5	1,750	1.5	.080
1N2822	50M27Z	27	460	2.8	90	5	1,500	1.5	.085
1N2823	50M30Z	30	420	3.0	90	5	1,400	1.5	.085
1N2824	50M33Z	33	380	3.2	90	5	1,300	1.5	.085
1N2825	50M36Z	36	350	3.5	90	5	1,150	1.5	.085
1N2826	50M39Z	39	320	4.0	90	5	1,050	1.5	.090
1N2827	50M43Z	43	290	4.5	90	5	975	1.5	.090
1N2829	50M47Z	47	270	5.0	100	5	880	1.5	.090
1N2831	50M51Z	51	245	5.2	100	5	810	1.5	.090
1N2833	50M62Z	62	200	7	120	5	660	1.5	.090
1N2834	50M68Z	68	180	8	140	5	600	1.5	.090
1N2835	50M75Z	75	170	9	150	5	540	1.5	.090
1N2836	50M82Z	82	150	11	160	5	490	1.5	.090
1N2837	50M91Z	91	140	15	180	5	420	1.5	.090
1N2838	50M100Z	100	120	20	200	5	400	1.5	.090
1N2840	50M110Z	110	110	30	220	5	365	1.5	.095
1N2841	50M120Z	120	100	40	240	5	335	1.5	.095
1N2842	50M130Z	130	95	50	275	5	310	1.5	.095
1N2843	50M150Z	150	85	75	400	5	270	1.5	.095
1N2844	50M160Z	160	80	80	450	5	250	1.5	.095
1N2845	50M180Z	180	68	90	525	5	220	1.5	.095
1N2846	50M200Z	200	65	100	600	5	200	1.5	.100

FIGURE 23

23.8 The nominal zener voltage is followed by a Z in the Motorola type number, indicating a zener diode. The number following the Z indicates the tolerance.

400

23.9 No number following the Z indicates 20% tolerance. A 10 following the Z indicates a 10% ____________________.

no answer needed

23.10 A 10M100Z10 is a ______________ watt, ______________ volt zener diode having a __________% voltage tolerance.

tolerance

23.11 The zener diode 10M100Z10 can have a zener voltage ranging from a low of ______________ volts to a high of ______________ volts.

10
100
10

COURTESY: MOTOROLA SEMICONDUCTOR PRODUCTS, INC., PHOENIX, ARIZONA

ELECTRICAL CHARACTERISTICS (@ 30°C Case unless otherwise specified)

JEDEC TYPE NUMBER	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} ohms	Z_{ZK} @ I_{ZK} ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage (V_F) Volts @$I_F = 2$ Amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2970	10M6.8Z	6.8	370	1.2	500	1.0	1,320	1.5	.040
1N2971	10M7.5Z	7.5	335	1.3	250	1.0	1,180	1.5	.045
1N2972	10M8.2Z	8.2	305	1.5	250	1.0	1,040	1.5	.048
1N2973	10M9.1Z	9.1	275	2.0	250	1.0	960	1.5	.051
1N2974	10M10Z	10	250	3	250	1.0	860	1.5	.055
1N2975	10M11Z	11	230	3	250	1.0	780	1.5	.060
1N2976	10M12Z	12	210	3	250	1.0	720	1.5	.065
1N2977	10M13Z	13	190	3	250	1.0	660	1.5	.065
1N2979	10M15Z	15	170	3	250	1.0	560	1.5	.070
1N2980	10M16Z	16	155	4	250	1.0	530	1.5	.070
1N2982	10M18Z	18	140	4	250	1.0	460	1.5	.075
1N2984	10M20Z	20	125	4	250	1.0	420	1.5	.075
1N2985	10M22Z	22	115	5	250	1.0	380	1.5	.080
1N2986	10M24Z	24	105	5	250	1.0	350	1.5	.080
1N2988	10M27Z	27	95	7	250	1.0	300	1.5	.085
1N2989	10M30Z	30	85	8	300	1.0	280	1.5	.085
1N2990	10M33Z	33	75	9	300	1.0	260	1.5	.085
1N2991	10M36Z	36	70	10	300	1.0	230	1.5	.085
1N2992	10M39Z	39	65	11	300	1.0	210	1.5	.085
1N2993	10M43Z	43	60	12	400	1.0	195	1.5	.090
1N2995	10M47Z	47	55	14	400	1.0	175	1.5	.090
1N2997	10M51Z	51	50	15	500	1.0	160	1.5	.090
1N2999	10M56Z	56	45	16	500	1.0	150	1.5	.090
1N3000	10M62Z	62	40	17	600	1.0	130	1.5	.090
1N3001	10M68Z	68	37	18	600	1.0	120	1.5	.090
1N3002	10M75Z	75	33	22	600	1.0	110	1.5	.090
1N3003	10M82Z	82	30	25	700	1.0	100	1.5	.090
1N3004	10M91Z	91	28	35	800	1.0	85	1.5	.090
1N3005	10M100Z	100	25	40	900	1.0	80	1.5	.090
1N3007	10M110Z	110	23	55	1,100	1.0	72	1.5	.095
1N3008	10M120Z	120	20	75	1,200	1.0	67	1.5	.095
1N3009	10M130Z	130	19	100	1,300	1.0	62	1.5	.095
1N3011	10M150Z	150	17	175	1,500	1.0	54	1.5	.095
1N3012	10M160Z	160	16	200	1,600	1.0	50	1.5	.095
1N3014	10M180Z	180	14	260	1,850	1.0	45	1.5	.095
1N3015	10M200Z	200	12	300	2,000	1.0	40	1.5	.100

JEDEC TYPE NO.	MOTOROLA TYPE NO.	Nominal Zener Voltage @ I_{ZT} (V_Z) Volts	Test Current (I_{ZT}) mA	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Max DC Zener Current 55°C Base (I_{ZM}) mA	Max Forward Voltage V_F @ 10 amps	Typical Zener Voltage Temp. Coeff. %/°C
1N2804	50M6.8Z	6.8	1850	0.2	70	5	6,600	1.5	.040
1N2805	50M7.5Z	7.5	1700	0.3	70	5	5,900	1.5	.045
1N2806	50M8.2Z	8.2	1500	0.4	70	5	5,200	1.5	.048
1N2807	50M9.1Z	9.1	1370	0.5	70	5	4,800	1.5	.051
1N2808	50M10Z	10	1200	0.6	80	5	4,300	1.5	.055
1N2809	50M11Z	11	1100	0.8	80	5	3,900	1.5	.060
1N2810	50M12Z	12	1000	1.0	80	5	3,600	1.5	.065
1N2811	50M13Z	13	960	1.1	80	5	3,300	1.5	.065
1N2813	50M15Z	15	830	1.4	80	5	2,800	1.5	.070
1N2814	50M16Z	16	780	1.6	80	5	2,650	1.5	.070
1N2816	50M18Z	18	700	2.0	80	5	2,300	1.5	.075
1N2818	50M20Z	20	630	2.4	80	5	2,100	1.5	.075
1N2819	50M22Z	22	570	2.5	80	5	1,900	1.5	.080
1N2820	50M24Z	24	520	2.6	80	5	1,750	1.5	.080
1N2822	50M27Z	27	460	2.8	90	5	1,500	1.5	.085
1N2823	50M30Z	30	420	3.0	90	5	1,400	1.5	.085
1N2824	50M33Z	33	380	3.2	90	5	1,300	1.5	.085
1N2825	50M36Z	36	350	3.5	90	5	1,150	1.5	.085
1N2826	50M39Z	39	320	4.0	90	5	1,050	1.5	.090
1N2827	50M43Z	43	290	4.5	90	5	975	1.5	.090
1N2829	50M47Z	47	270	5.0	100	5	880	1.5	.090
1N2831	50M51Z	51	245	5.2	100	5	810	1.5	.090
1N2833	50M62Z	62	200	7	120	5	660	1.5	.090
1N2834	50M68Z	68	180	8	140	5	600	1.5	.090
1N2835	50M75Z	75	170	9	150	5	540	1.5	.090
1N2836	50M82Z	82	150	11	160	5	490	1.5	.090
1N2837	50M91Z	91	140	15	180	5	420	1.5	.090
1N2838	50M100Z	100	120	20	200	5	400	1.5	.090
1N2840	50M110Z	110	110	30	220	5	365	1.5	.095
1N2841	50M120Z	120	100	40	240	5	335	1.5	.095
1N2842	50M130Z	130	95	50	275	5	310	1.5	.095
1N2843	50M150Z	150	85	75	400	5	270	1.5	.095
1N2844	50M160Z	160	80	80	450	5	250	1.5	.095
1N2845	50M180Z	180	68	90	525	5	220	1.5	.095
1N2846	50M200Z	200	65	100	600	5	200	1.5	.100

FIGURE 23

23.12 The a-c impedance of the 10M100Z is ________________ ohms at the nominal zener voltage and test current.

90
110

23.13** A 1N2835 can pass a maximum of ______________ma of zener current (at 55°C), and dissipate ______________ watts of power (at 30°C), and has a nominal zener voltage of _____________ volts. (Refer to figure 23.)

40

23.14 END OF SET

540
50
75

24 Some diodes designed for power rectifier service have controlled doping for a predictable ________________ breakdown voltage. This gives the added advantage of peak inverse ________________.

24.1 Controlling the doping levels and the geometry of the junction of power rectifier diodes allows the reverse breakdown point to be controlled as with the ________________ diode.

reverse
clipping or limiting

24.2 If the applied voltage swings above the reverse breakdown of the diode, clipping occurs. During clipping, the current is limited by the ____________ ________________ in the circuit.

zener

24.3 Such a diode will serve as a rectifier and give the added advantage of peak ______________ ________________.

series resistance

24.4 Power rectifiers with predictable reverse breakdown voltages may be used to set voltage levels or clip at a given voltage where the accuracy is not too critical.

inverse (reverse) limiting (clipping)

24.5 Sometimes termed an avalanche diode, this device may be used to insure that the output point of a vacuum tube or transistor circuit does not swing beyond an approximate level (as an example).

no answer needed

24.6 Constructing a power rectifier with a predictable reverse breakdown voltage combines some of the characteristics of the _______________ diode with the power rectifier.

no answer needed

24.7** Diodes with predictable reverse breakdown voltage, while designed to function as rectifiers, give the added advantage of ____________________ ____________________ ____________________.

zener

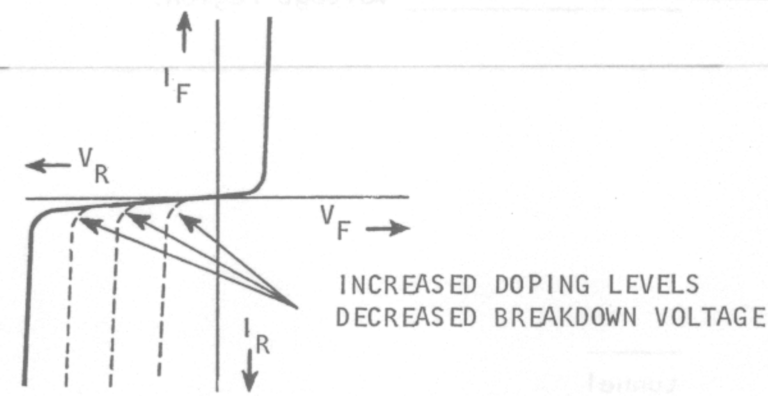
24.8 END OF SET

peak inverse limiting

25 Sufficient impurities can be added to an intrinsic semiconductor forming a PN junction that is in tunnel breakdown with zero bias applied and does not come out of breakdown until a value of ________________ bias is applied. ________________ and ________________ diodes are formed in this fashion.

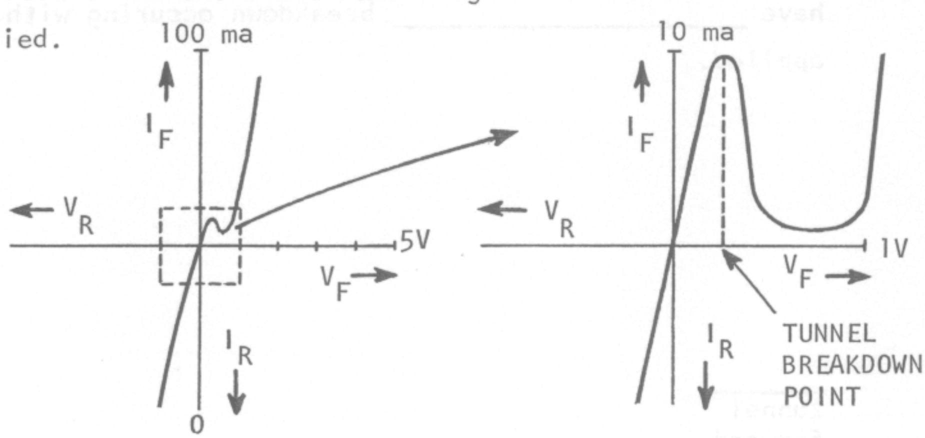
forward
tunnel
backward

25.1 Increasing the amount of doping impurities used to form the PN junction reduces the voltage level at which the diode enters breakdown. Breakdown occuring below approximately 6 volts is generally due to ______________.

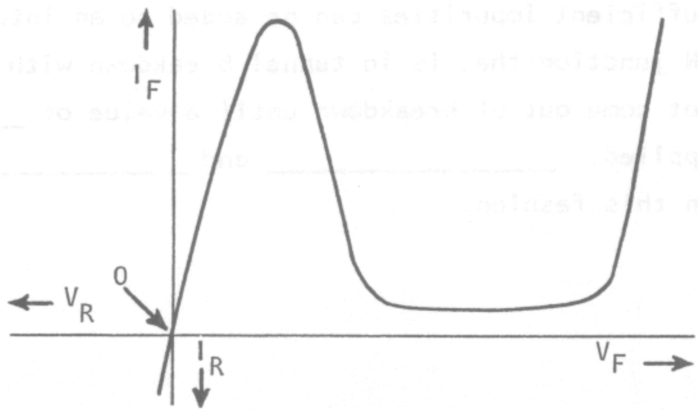


tunneling

25.2 Increasing the doping levels beyond the point where breakdown occurs at zero volts, results in the diode remaining in breakdown with forward voltage applied.



25.3 The diode conducts readily with either forward or reverse voltage applied when ________________ breakdown occurs in the forward voltage region of the EI curve.



no answer needed

25.4 The diode exhibits a near zero volt turn-on characteristic when doped heavy enough to have ________________ breakdown occuring in the ________________ voltage region.

tunnel

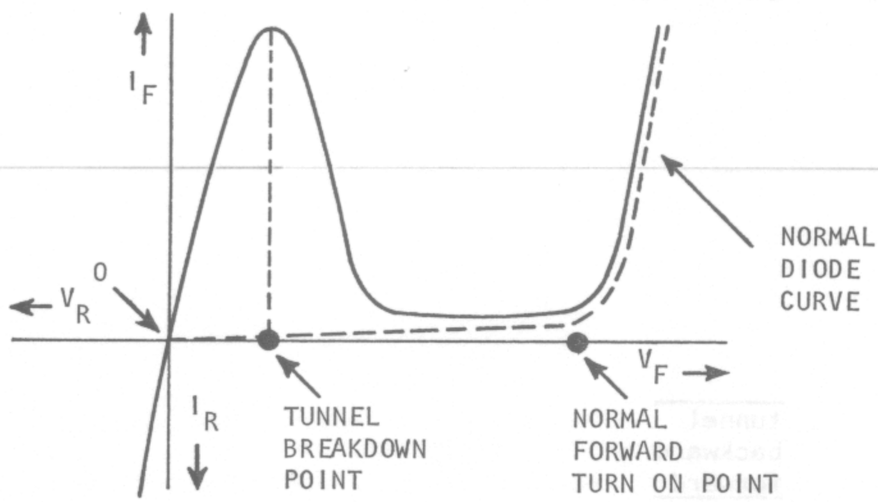
25.5 Tunnel diodes and backward diodes are both heavily doped junctions that have ________________ breakdown occuring with forward voltage applied.

tunnel
forward

25.6 An EI curve of a diode showing the diode in tunnel breakdown with forward bias applied must be for a ________________ or a ________________ diode.

tunnel

25.7 Tunnel diodes and backward diodes are doped with sufficient impurities to cause tunnel breakdown to occur between the ______________ volts point and the normal forward turn on voltage point.



tunnel
backward

25.8 The tunnel and the backward diode are constructed in much the same fashion. Heavy doping causes a very ____________ junction and enhances
(narrow, wide)
________________ breakdown.

zero

25.9** ____________________ diodes and ____________________ diodes are formed by heavy doping, causing the tunnel breakdown point to occur in the

________________ bias region.
(forward, reverse)

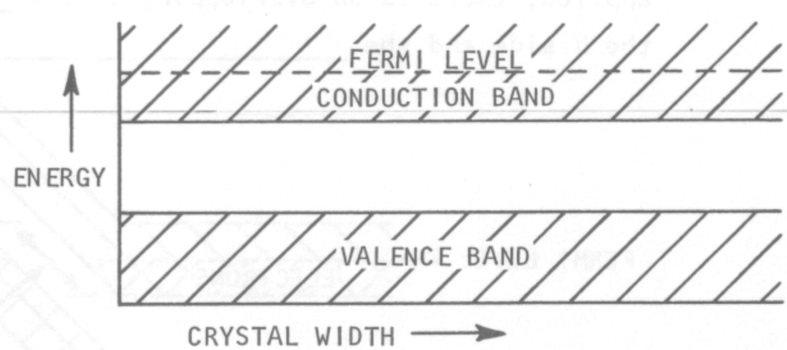
narrow
tunnel

25.10 END OF SET

tunnel
backward
forward

26 Tunnel diodes are so heavily doped that the fermi levels are moved into the ______________ band in the N side and into the ______________ band in the P side. The fermi levels must line up for a state of balance or equilibrium to exist, and in a tunnel diode the bands of the two sides ______________ when the diode is at equilibrium.

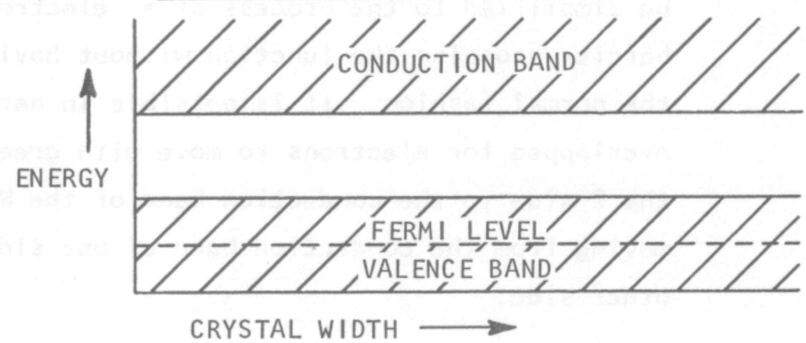
26.1 The tunnel diode has the ______________ side doped heavy enough to move the fermi level into the ______________ band as shown in the diagram.



conduction
valence
overlap

SEMICONDUCTOR HEAVILY DOPED
WITH DONOR INPURITIES

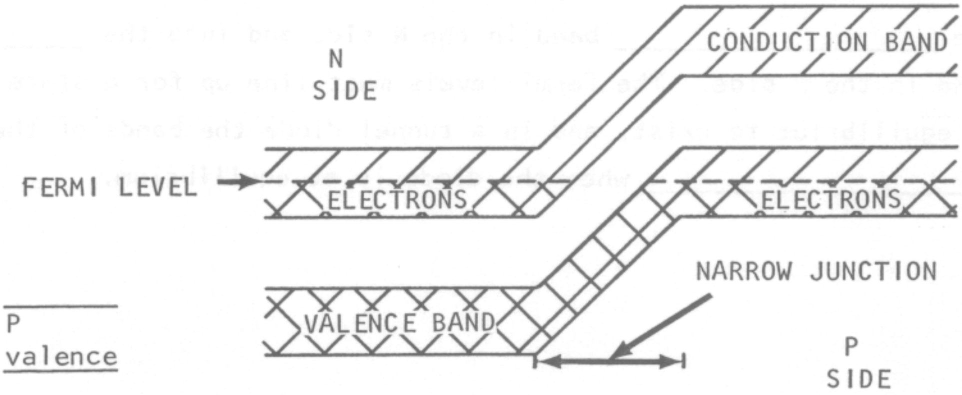
26.2 The tunnel diode has the ______________ side doped heavy enough to move the fermi level into the ______________ band as shown in the diagram.



N
conduction

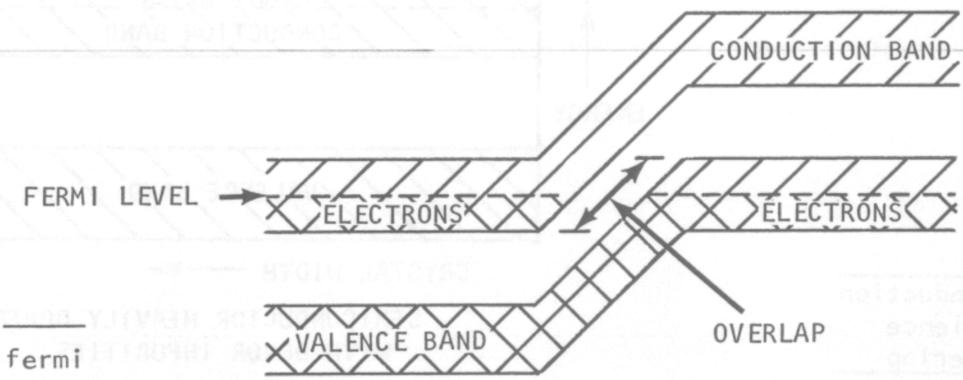
SEMICONDUCTOR HEAVILY DOPED
WITH ACCEPTOR IMPURITIES

26.3 When the tunnel diode junction is formed, the ________________ levels must line up at zero bias.



P
valence

26.4 With the tunnel diode fermi levels lined up with no external energy applied, there is an overlapping of the ____________________ band in the N side and the ______________________ band in the P side.



fermi

26.5 For this program, the process known as "quantum mechanical tunneling" will be simplified to the process of an electron on one side of the junction or barrier crossing the junction without having sufficient energy to do so in the normal fashion. It is possible in narrow junctions when the bands are overlapped for electrons to move with great speed from the valence band of the P side to the conduction band of the N side and vice versa, instead of moving from the conduction band of one side to the conduction band of the other side.

conduction
valence

26.6 With no external energy applied, carriers are sitting at the same energy levels on both sides of the junction. Tunneling takes place in both directions by the same amount, and the net current flow is ______________.

no answer needed

26.7** Tunnel diodes are formed by doping N and P sides into a semiconductor so heavily that the fermi level is in the conduction band of the __________ side, and in the valence band of the ____________ side, and these two bands ____________________ at zero bias.

zero

26.8 END OF SET

N
P
overlap

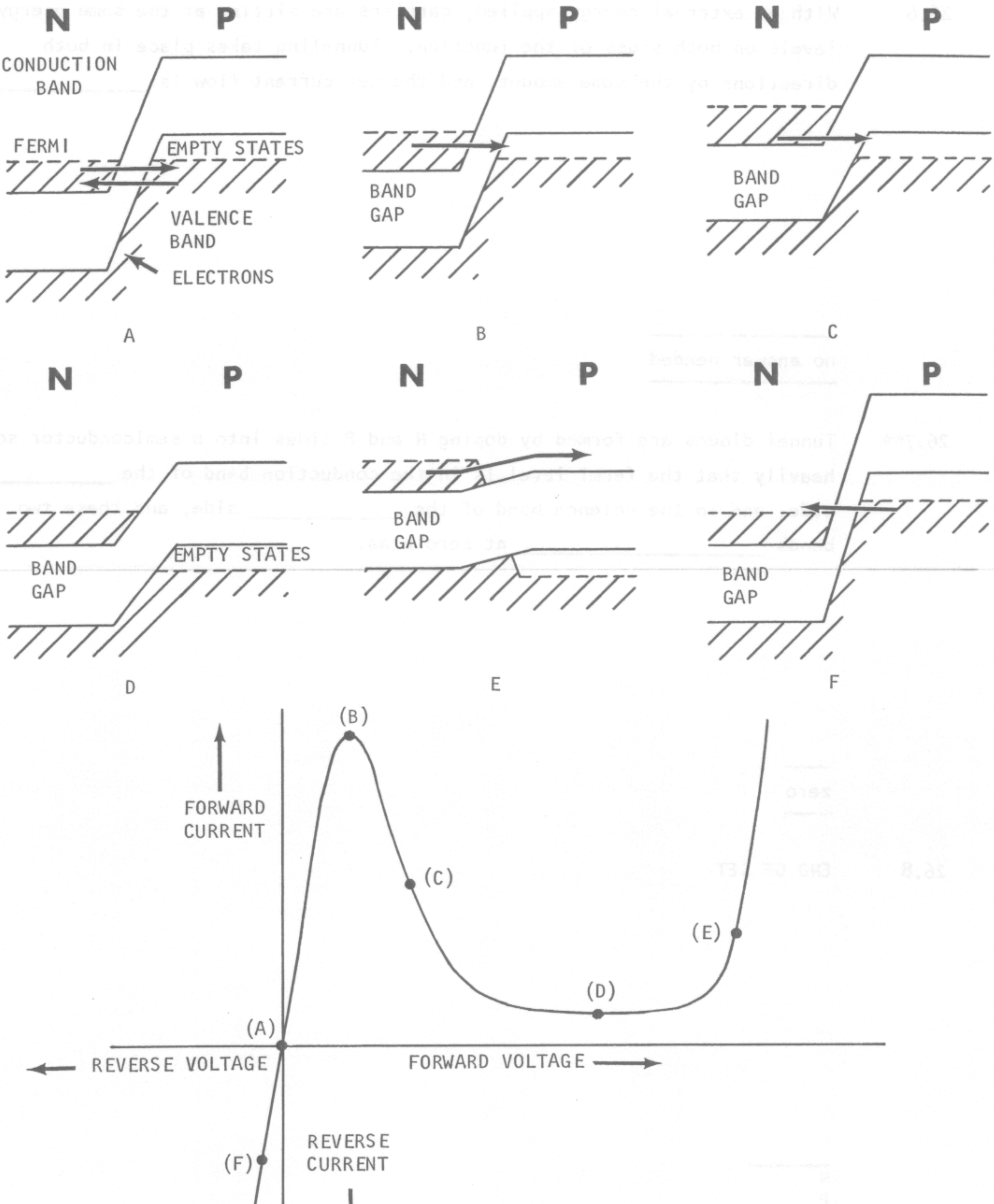

N
P
CONDUCTION
BAND
FERMI
EMPTY STATES
VALENCE
BAND
ELECTRONS
A
N
P
BAND
GAP
B
N
P
BAND
GAP
C
N
P
EMPTY STATES
BAND
GAP
D
N
P
BAND
GAP
E
N
P
BAND
GAP
F
(B)
FORWARD
CURRENT
(C)
(E)
(D)
(A)
REVERSE VOLTAGE
FORWARD VOLTAGE
(F)
REVERSE
CURRENT

FIGURE 27

27 Tunneling at zero bias is possible when there is an ______________ of the energy bands. The negative resistance region of the tunnel diode curve occurs as the bands __________________ when __________________ bias is applied. Reverse bias results in an increase in tunneling from the _________________ to the _________________ side.

27.1 Figure 27A is the energy band diagram of a tunnel diode at equilibrium. The _______________ levels are alligned, and the net current is _________________.

overlap
uncross
forward
P
N

27.2 The net current is zero in figure 27A, because the number of ___________ electrons is the same from N to P material and vice-versa.

fermi
zero

27.3 For this program, the process known as "quantum mechanical tunneling" will be simplified to the process of an electron on one side of the junction or barrier crossing the junction without having sufficient energy to do so in the normal fashion. It is possible in narrow junctions when the bands are overlapped for electrons to move with great speed from the valence band of the P side to the conduction band of the N side and vice-versa, instead of moving from the conduction band of one side to the conduction band of the other side.

tunneling

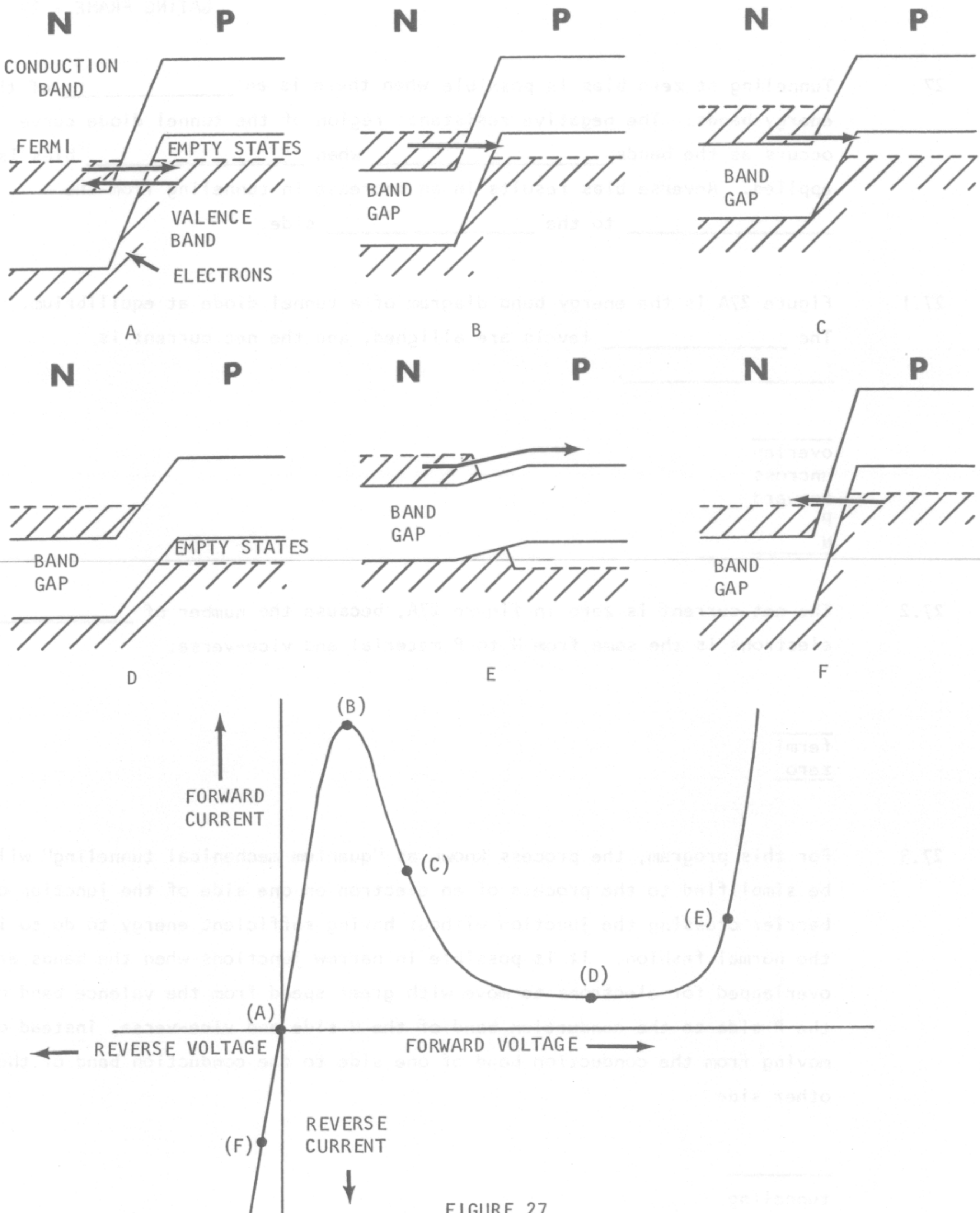

N
P
CONDUCTION BAND
FERMI
EMPTY STATES
VALENCE BAND
ELECTRONS
A
BAND GAP
B
C
D
E
F
FORWARD CURRENT
REVERSE CURRENT
REVERSE VOLTAGE
FORWARD VOLTAGE
(A)
(B)
(C)
(D)
(E)
(F)

FIGURE 27

27.4 Figure 27B has a small amount of forward bias applied, and increased tunneling is enhanced from the ________________ side to the __________ side.

no answer needed

27.5 Tunneling from the N side to the P side is increased with application of a small __________________ bias.

N
P

27.6 The net current is no longer zero, but depends on the increase in the number of electrons that ___________________ as a result of the application of forward bias.

forward

27.7 The letter designations on the tunnel diode EI curve in figure 27 indicate the points on the curve that correspond to the energy band diagram marked with the same letter.

tunnel

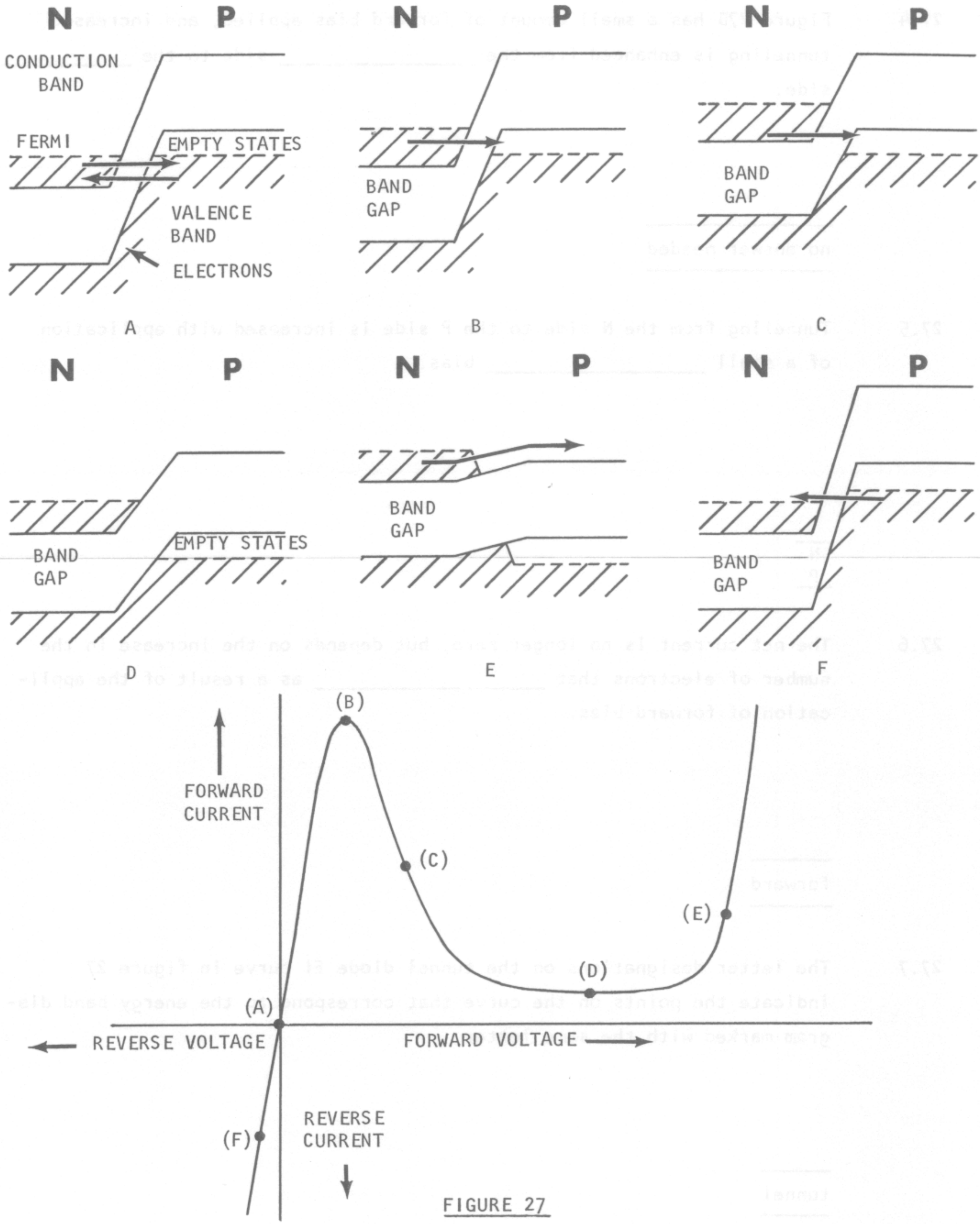

N
P
CONDUCTION BAND
FERMI
EMPTY STATES
VALENCE BAND
ELECTRONS
A
N
P
BAND GAP
B
N
P
BAND GAP
C
N
P
BAND GAP
EMPTY STATES
D
N
P
BAND GAP
E
N
P
BAND GAP
F
FORWARD CURRENT
(B)
(C)
(E)
(D)
(A)
REVERSE VOLTAGE
FORWARD VOLTAGE
(F)
REVERSE CURRENT

FIGURE 27

27.8 Figure 27C has sufficient forward bias applied to start uncrossing the bands. Part of the conduction band of the N side has been lifted opposite the band ______________.

no answer needed

27.9 Tunneling is reduced when the bands start to uncross. The current will start to ____________________ with the condition in figure 27C.
(increase, decrease)

gap

27.10 A further increase in forward bias, as shown in figure 27D, results in the complete uncrossing of the bands, and current falls to its ___________ value.

decrease

27.11 A still further increase in forward bias lifts the ________________ band of the N side opposite the conduction band of the P side, and normal diode forward current results, as shown in figure 27E.

minimum

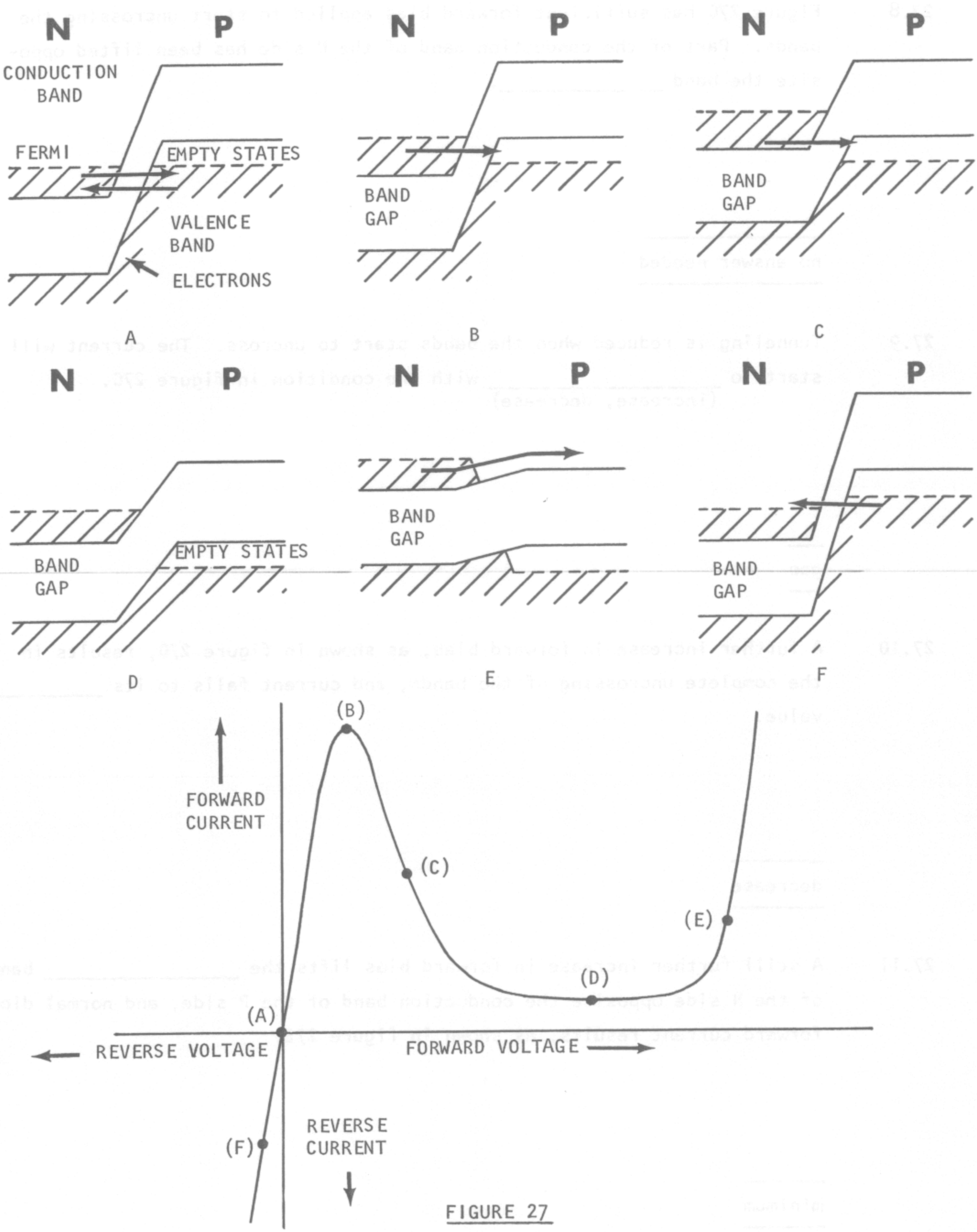

N
P
CONDUCTION
BAND
FERMI
EMPTY STATES
VALENCE
BAND
ELECTRONS
A
N
P
BAND
GAP
B
N
P
BAND
GAP
C
N
P
BAND
GAP
EMPTY STATES
D
N
P
BAND
GAP
E
N
P
BAND
GAP
F
(B)
FORWARD
CURRENT
(C)
(E)
(D)
(A)
REVERSE VOLTAGE
FORWARD VOLTAGE
(F)
REVERSE
CURRENT

FIGURE 27

27.12 The portion of the diode curve in figure 27 between points B and D has current decreasing with an increase in voltage. This represents a ________________ resistance or conductance.
(negative, positive)

conduction

27.13 Figure 27F has reverse bias applied, and tunneling is increased from the ________________ side to the ________________ side.

negative

27.14 The complete EI curve in figure 27 shows the tunnel diode turning on at or near zero volts of ________________ or ________________ voltage.

P
N

27.15 The portion of the EI curve (in figure 27) from A to F and from A to B represents a ________________ resistance, while the portion from B to D represents a ________________ resistance, and then the portion from D on once again represents a ________________ resistance.

forward
reverse

27.16 At zero bias, the tunnel diode has the conduction band of the N side and the valence band of the P side overlapped and separated by a

____________ junction.
(wide, narrow)

---

positive
negative
positive

27.17 The ________________ of the bands at zero bias enhances tunneling. Application of ______________ voltage increases tunneling from the
(forward, reverse)
N to the P side.

---

narrow

27.18** A tunnel diode has the conduction band of the N side and the valence band of the P side ____________________ at zero bias. As forward voltage is applied, the bands uncross and a negative ________________ characteristic results. Further increase in __________________ voltage after the bands are uncrossed results in normal diode current. The tunnel diode turns on at near zero volts of ____________________ or ____________________ voltage.

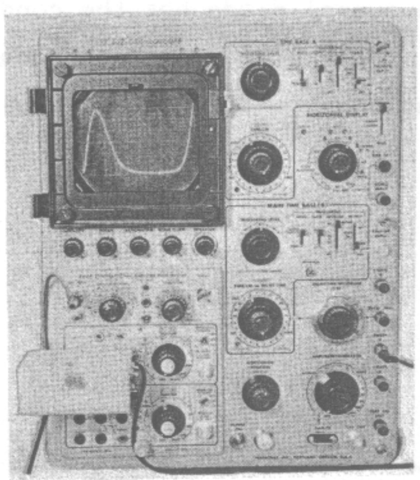
---

overlap
forward

27.19 END OF SET

---

overlapped, opposite one another
resistance or conductance
forward
forward
reverse



TEST SET-UP: TEKTRONIX TYPE 547 OSCILLOSCOPE, TYPE "O" OPERATIONAL AMPLIFIER PLUG-IN WITH TUNNEL DIODE DRIVER ADAPTER*. PHOTO BELOW TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.

* NON-PRODUCTION ITEM

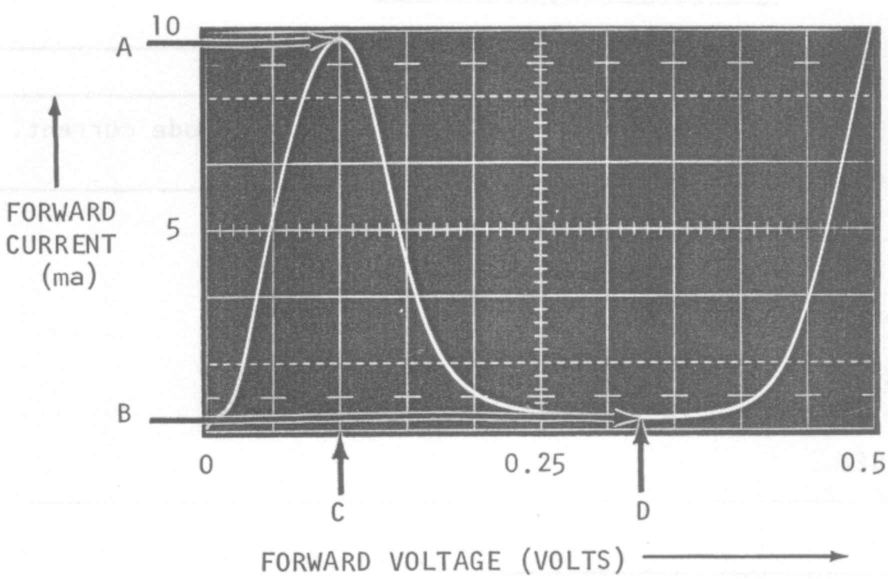


FIGURE 28

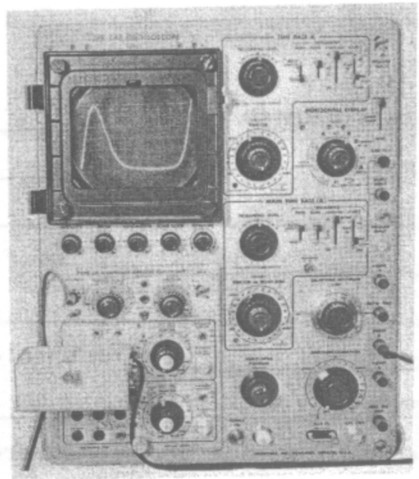
28 Point A in figure 28 is termed ____________ ____________, and its magnitude is determined by junction ________________. Point B is termed ____________ ____________, and its magnitude is a measure of the ________________ of the tunnel diode. Point C is termed ____________ ____________, and Point D is termed ____________ ____________. Both of their magnitudes are determined by the type of ________________ used. The portion of the tunnel diodes EI curve between C and D represents a ________________ resistance or conductance.

28.1 Point A in figure 28 is the point at which the bands start to uncross. Tunnel current is at its peak and the magnitude at this point is termed ________________ current.

peak current
geometry, size, etc.
valley current
merit, etc.
peak voltage
valley voltage
semiconductors
negative

28.2 Peak current magnitude is dependent on the number of electrons that can tunnel. A large junction cross section will allow ____________ (more, less) electrons to tunnel than a small cross section.

peak



TEST SET-UP: TEKTRONIX TYPE 547 OSCILLOSCOPE, TYPE "O" OPERATIONAL AMPLIFIER PLUG-IN WITH TUNNEL DIODE DRIVER ADAPTER*. PHOTO BELOW TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.

* NON-PRODUCTION ITEM

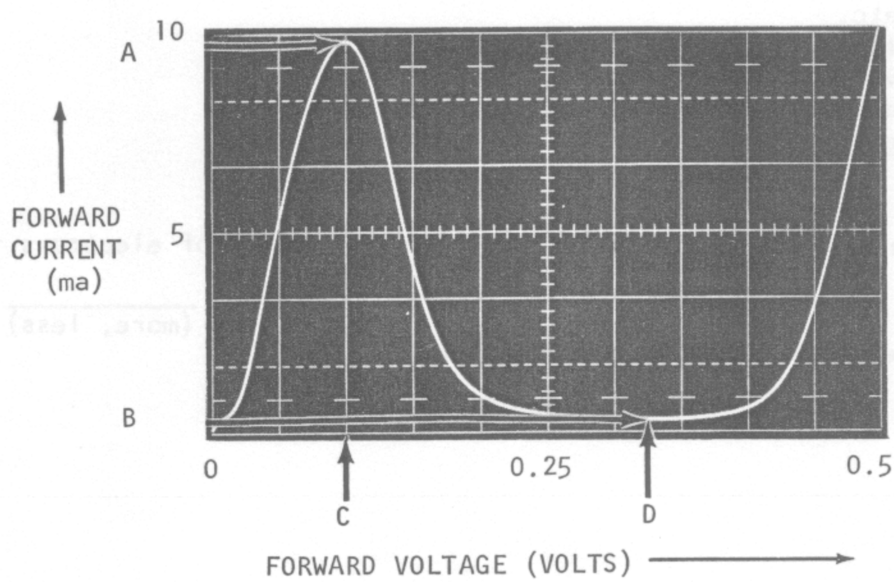


FIGURE 28

28.3 Peak current magnitude is determined by the geometry of the junction. Tunnel diodes are etched to size, and this sets the value of ___________ ________________.

more

28.4 Point B in figure 28 is termed valley current. This is the point of minimum current as the bands uncross. It gets its name because it lies in the _________________________ between the two slopes.

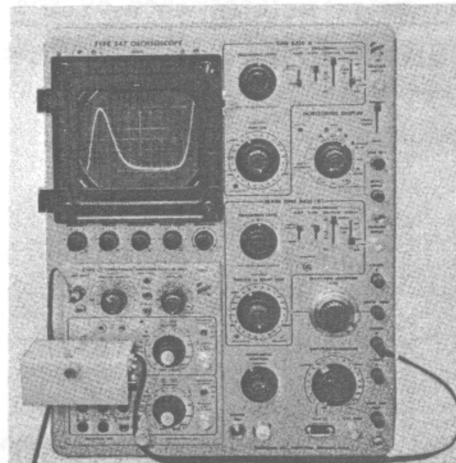
peak current

28.5 Point C in figure 28 is the voltage point at which peak current occurs and is termed ________________ ____________________.

valley

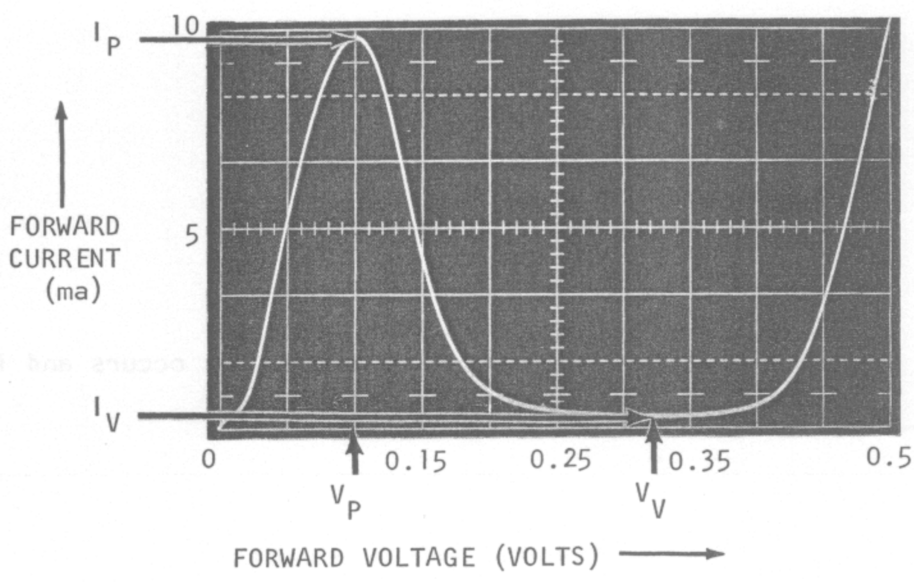
28.6 Point D is the voltage point at which valley current occurs and is termed ___________________ ____________________.

peak voltage



TEST SET-UP: TEKTRONIX TYPE 547 OSCILLOSCOPE, TYPE "O" OPERATIONAL AMPLIFIER PLUG-IN WITH TUNNEL DIODE DRIVER ADAPTER*. PHOTO BELOW TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.

* NON-PRODUCTION ITEM



TUNNEL DIODE EI CURVE

FIGURE 28A

28.7 The type of semiconductor used determines the magnitude of peak and valley voltage. Typical peak and valley voltage for germanium tunnel diodes are 100 mvolts and 350 mvolts respectively.

valley voltage

28.8 The EI curve in figure 28A __________ (is, is not) for a germanium tunnel diode.

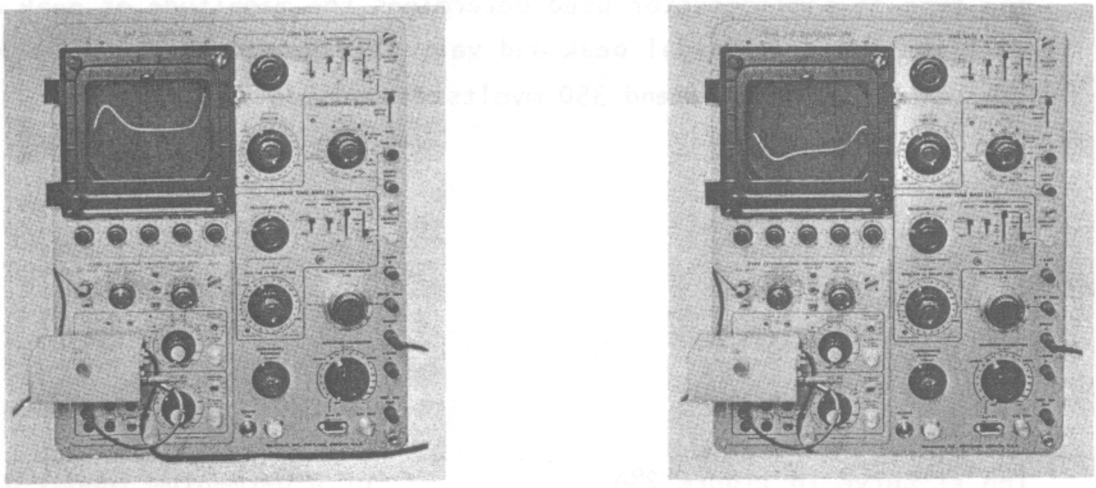
no answer needed

28.9 Figure 28A is an EI curve of a germanium tunnel diode. V_P (peak voltage) is approximately ______________ mvolts, and V_V (valley voltage) is approximately ______________ mvolts.

is

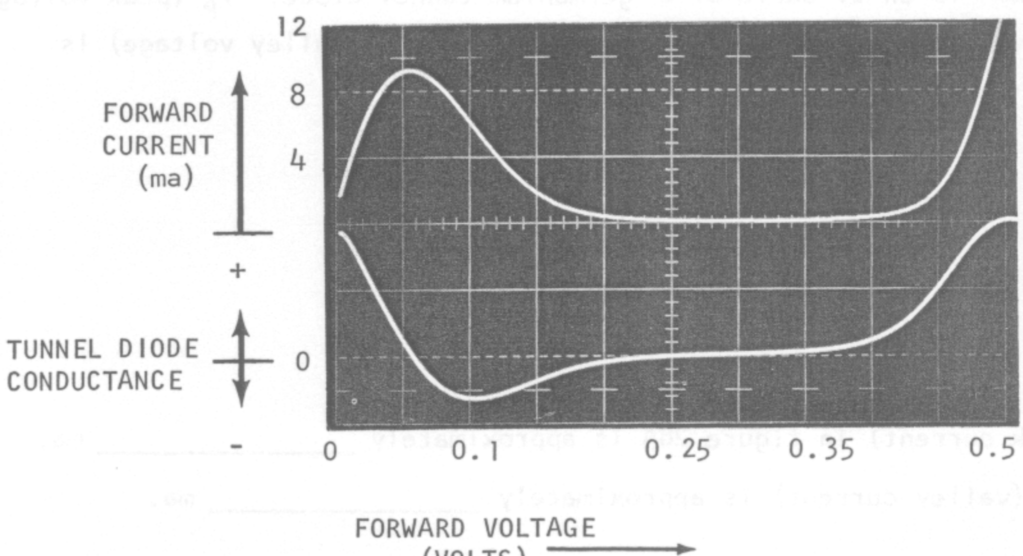
28.10 I_P (peak current) in figure 28A is approximately ______________ ma, and I_V (valley current) is approximately ______________ ma.

100
325



TEST SET-UP: TEKTRONIX TYPE 547 OSCILLOSCOPE, TYPE "O" OPERATIONAL AMPLIFIER PLUG-IN WITH TUNNEL DIODE DRIVER ADAPTER*. PHOTO BELOW TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.

* NON-PRODUCTION ITEM



DOUBLE EXPOSURE SHOWING TUNNEL DIODE EI CURVE (TOP) AND CONDUCTANCE CURVE (BOTTOM)

FIGURE 28B

28.11 Figure 28B indicates that the peak current point is the point of change from a positive to a ________________ conductance.

10
0.5

28.12 The negative conductance (or resistance) portion of the tunnel diode curve occurs between ________________ voltage and ________________ voltage.

negative

28.13 The negative conductance changes to a ________________ conductance at the valley current point, as shown in figure 28B.

peak
valley

28.14 The amount of noise generated in the tunnel diode appears to be related to the amount of valley current flowing. The greater the magnitude of valley current, the greater the ________________.

positive

28.15 The magnitude of negative conductance depends on the ratio of peak current to valley current. The lower the magnitude of ________________ current, the better the tunnel diode in most cases.

noise

28.16 A figure of merit for a tunnel diode is the magnitude of ________________ current.

valley

28.17** The magnitude of peak current is determined by junction ________________. Valley current magnitude is a figure of ________________ of the tunnel diode. ________________ voltage and ________________ voltage magnitudes are determined by the type of semiconductor used. The portion of the tunnel diodes operation between peak current and valley current is an area of ________________ conductance or resistance.

valley

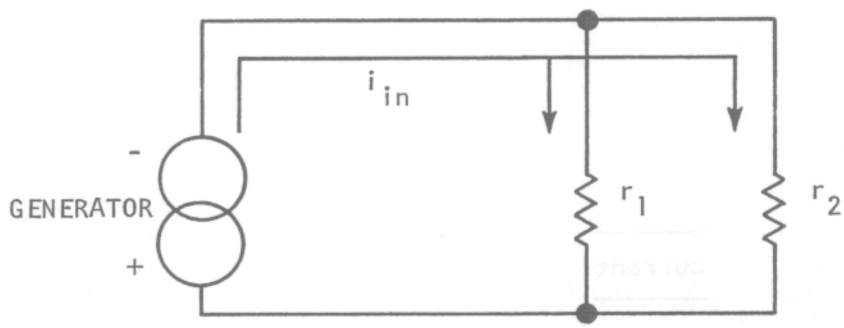
28.18 END OF SET

geometry, cross section, etc.
merit
peak
valley
negative

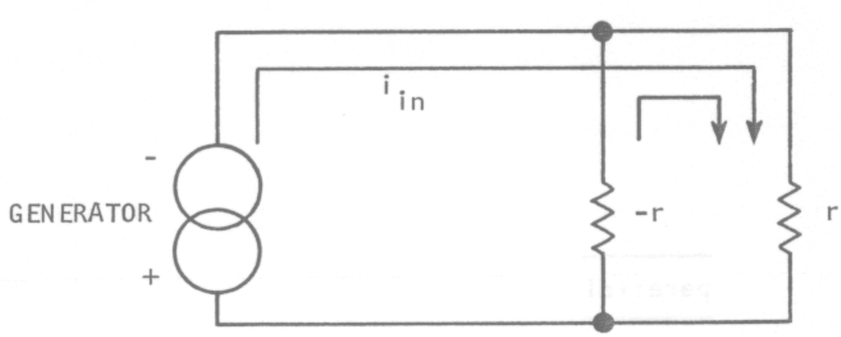
29 If a positive resistance is definied as a resistance that dissipates power, then a negative resistance can be defined as a resistance that will ____________ power. Operated in the ____________ resistance region, the tunnel diode can serve as an amplifier, with either a ____________ or ____________ connection with a positive resistance.

29.1 A generator supplying current to two positive resistances as shown will have total current distributed between the two resistances. The voltage across the two resistors will be the same.

generate
negative
series
parallel

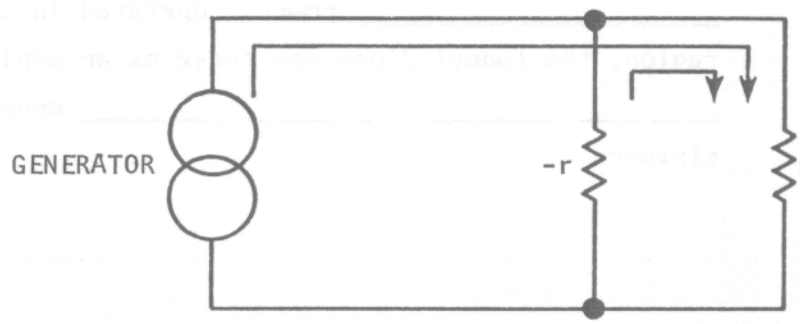


29.2 A generator supplying current to a positive and a negative resistance, as shown, finds the ____________ resistance supplying current to the ____________ resistance. The current in the positive resistor can be greater than the input current.



no answer needed

29.3 Current gain can be accomplished by driving a positive resistance in parallel with a negative resistance. Since the voltage across the resistors is the same as that across the input generator, only __________ gain is possible.



negative
positive

29.4 A negative resistance generates power, allowing amplification. A ________________ connection of a negative and positive resistance allows current gain.

current

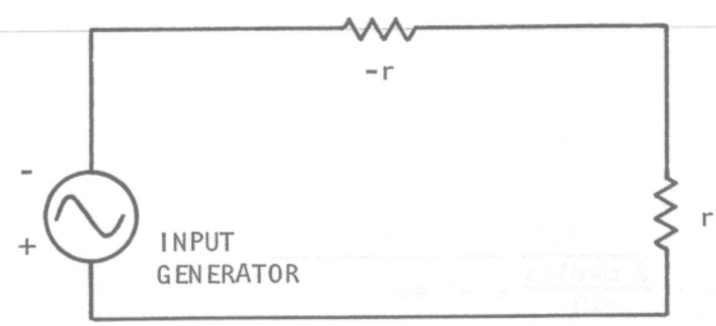
29.5 The tunnel diode operated in the proper portion of its characteristics will serve as a negative resistance, and will give current gain when placed in __________________ with a positive resistance and properly biased.

parallel

29.6 The tunnel diode operated as a parallel amplifier will offer a power gain equal to the ______ (current, voltage) gain, since the ______ (current, voltage) gain is unity.

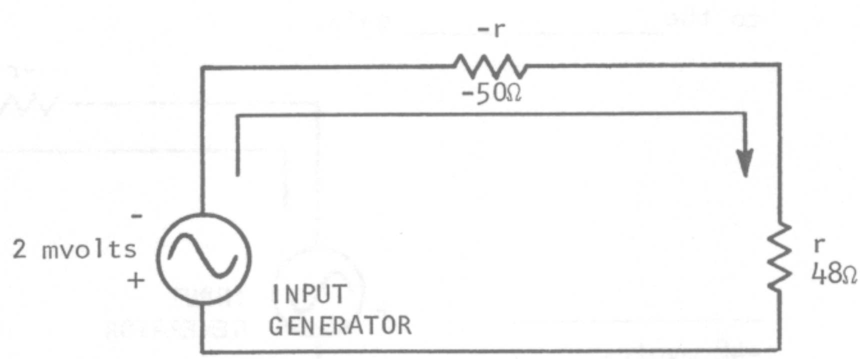
parallel

29.7 A tunnel diode placed in series with a positive resistance as shown, shows the generator a resistance which is the algebraic ______ of the positive and negative resistance.



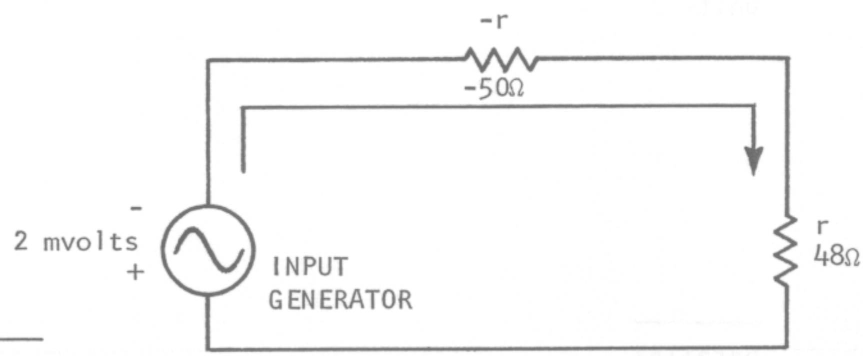
current
voltage

29.8 In the circuit shown, the input generator sees ______ ohms of resistance.



sum

29.9 The current in the circuit shown is ____________ ma and will develop ____________ volts across the positive resistance.



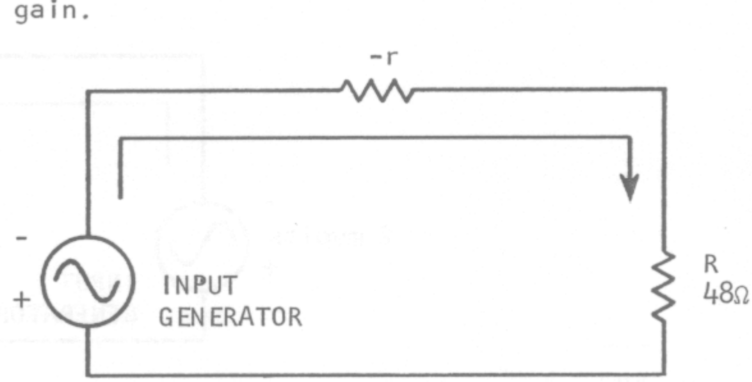
$48\Omega + (-50\Omega) = -2\Omega$

29.10 Since there is -48 mvolts across the positive resistance and an input of 2 mvolts, a voltage gain of ____________ has occurred.

$\frac{2 \text{ mvolts}}{-2\Omega} = -1 \text{ ma}$

$-1 \text{ ma} \times 48\Omega = -48 \text{ mvolts}$

29.11 Since the current through the resistors and the input generator is the same, current gain is ________________, and power gain is proportional to the ____________ gain.



$\frac{-48 \text{ mvolts}}{2 \text{ mvolts}} = -24$

29.12 A negative resistance in ____________________ with a positive resistance can offer voltage gain.

unity, one
voltage

29.13 A tunnel diode can serve as the negative resistance if properly biased in a proper circuit and, when placed in series with a positive resistance, offers ________________ gain.
(current, voltage)

series

29.14** A ____________________ resistance can be defined as a resistance that generates power, while a ___________________ resistance is defined as a resistance that dissipates power. A tunnel diode has a negative resistance characteristic and, in ___________________ with a positive resistance, can offer current gain.

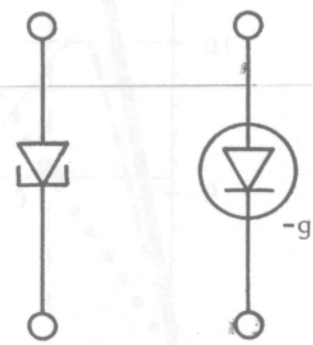
voltage

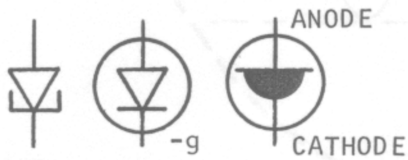
29.15 END OF SET

negative
positive
parallel

30 ____________________ is the symbol for a tunnel diode. When used as an amplifier, the combination of the negative and positive conductances must give a resultant conductance that is __________________ (negative, positive). This requires that the positive resistance be ______________ (greater, less) than the negative resistance of the tunnel diode. Tunnel diodes, as amplifiers, are limited to ___________________ frequency operation.

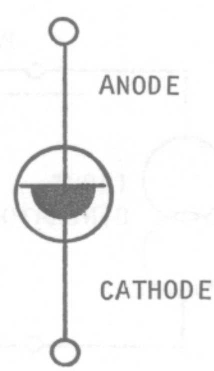
30.1 In most diagrams, the normal diode symbol is modified by the addition of lines to indicate a tunnel, or a -g to indicate negative conductance.





positive
less
high

30.2 The symbol shown is also used to indicate the tunnel diode. The small rounded portion of the symbol represents the ________________________.



no answer needed

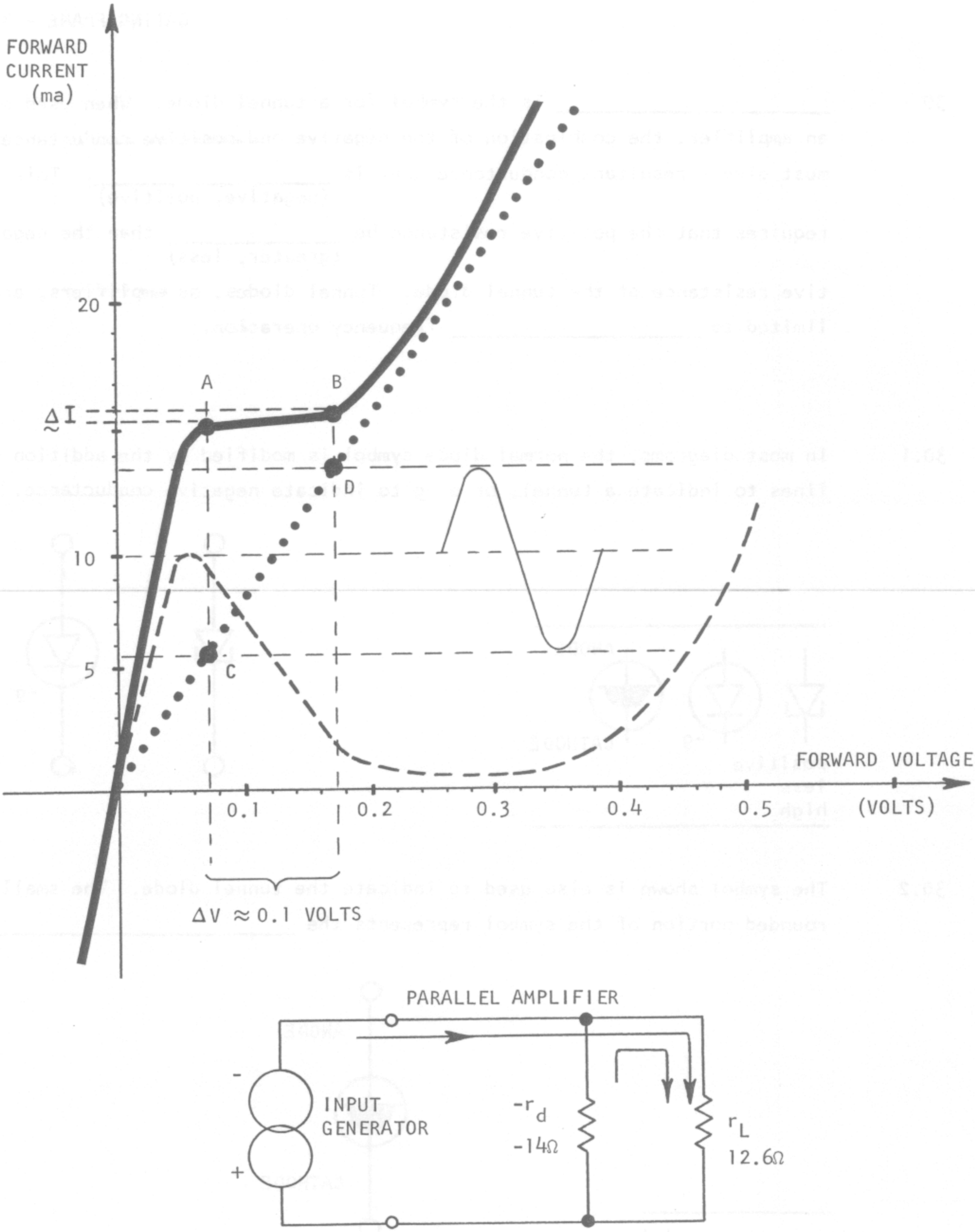

FORWARD CURRENT (ma)
20
10
5
A
B
C
D
ΔI
FORWARD VOLTAGE
(VOLTS)
0.1
0.2
0.3
0.4
0.5
ΔV ≈ 0.1 VOLTS
PARALLEL AMPLIFIER
INPUT GENERATOR
-
+
-r_d
-14Ω
r_L
12.6Ω

FIGURE 30

30.3 When used as an amplifier, the combination of the positive and negative conductances must give a resultant positive conductance. This means the ______________ resistance must be the larger of the two.

cathode

30.4 A requirement for tunnel diode amplifier operation is that the ______________ ______________ in the circuit be less than the negative resistance of the tunnel diode.

negative

30.5 If the positive resistance is equal to or greater than the diodes negative resistance, the diode will switch between the positive slopes, as it cannot enter the negative ______________ region.

positive resistance

30.6 In figure 30, the dashed curve is the tunnel diode curve, the dotted line is the resistors EI characteristic, and the solid curve is the combination of their characteristics when they are placed in parallel. To serve as an amplifier, A to B must represent a ______________ conductance.

resistance (or conductance)

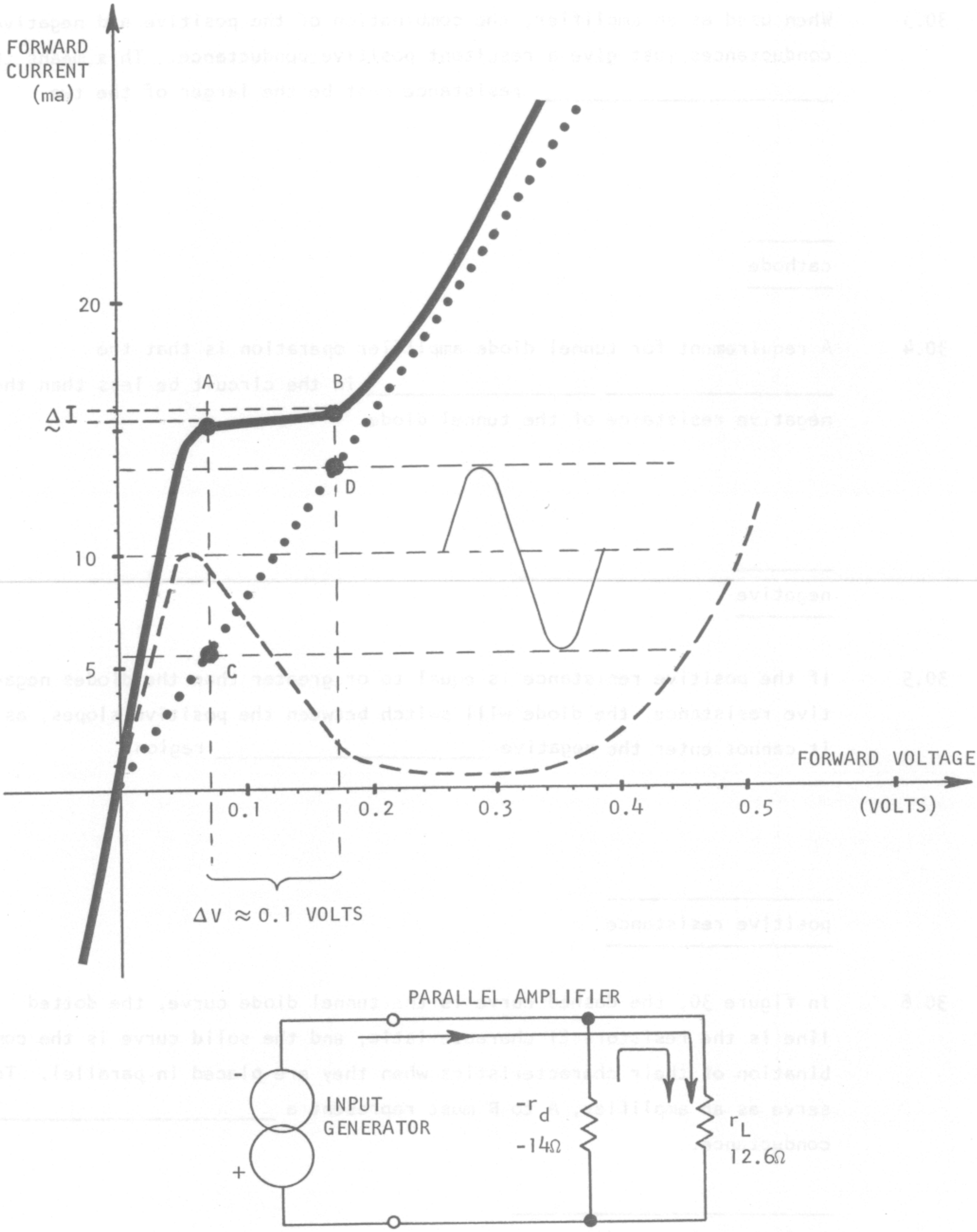

FORWARD CURRENT (ma)
20
10
5
A
B
ΔI
D
C
FORWARD VOLTAGE
0.1
0.2
0.3
0.4
0.5
(VOLTS)
ΔV ≈ 0.1 VOLTS
PARALLEL AMPLIFIER
INPUT GENERATOR
-
+
$-r_d$
-14Ω
r_L
12.6Ω

FIGURE 30

30.7 The negative resistance of the diode in figure 30 is greater than the positive resistance. Small changes in the input current cause ________________ changes in the output or load current.
(the same, larger)

____
positive
____

30.8 The load resistor of 12.6Ω in figure 30 has a conductance (g_L) of 79,400 μmhos, and the negative conductance ($-g_d$) of the tunnel diode is 71,400 μmhos. The conductance of the parallel combination is a ________________ ______________ μmhos.
(negative, positive)

______
larger
______

30.9 The sum of the conductances in parallel give the slope of the resultant curve between A and B in figure 30. A conductance of 8000 μmhos is a resistance of ____________________ ohms.

____
positive
8000
____

30.10 The generator driving the tunnel diode circuit in figure 30 sees an input resistance of ____________________ ohms.

____

$$\frac{1}{8000 \times 10^{-6}} = 125$$

____

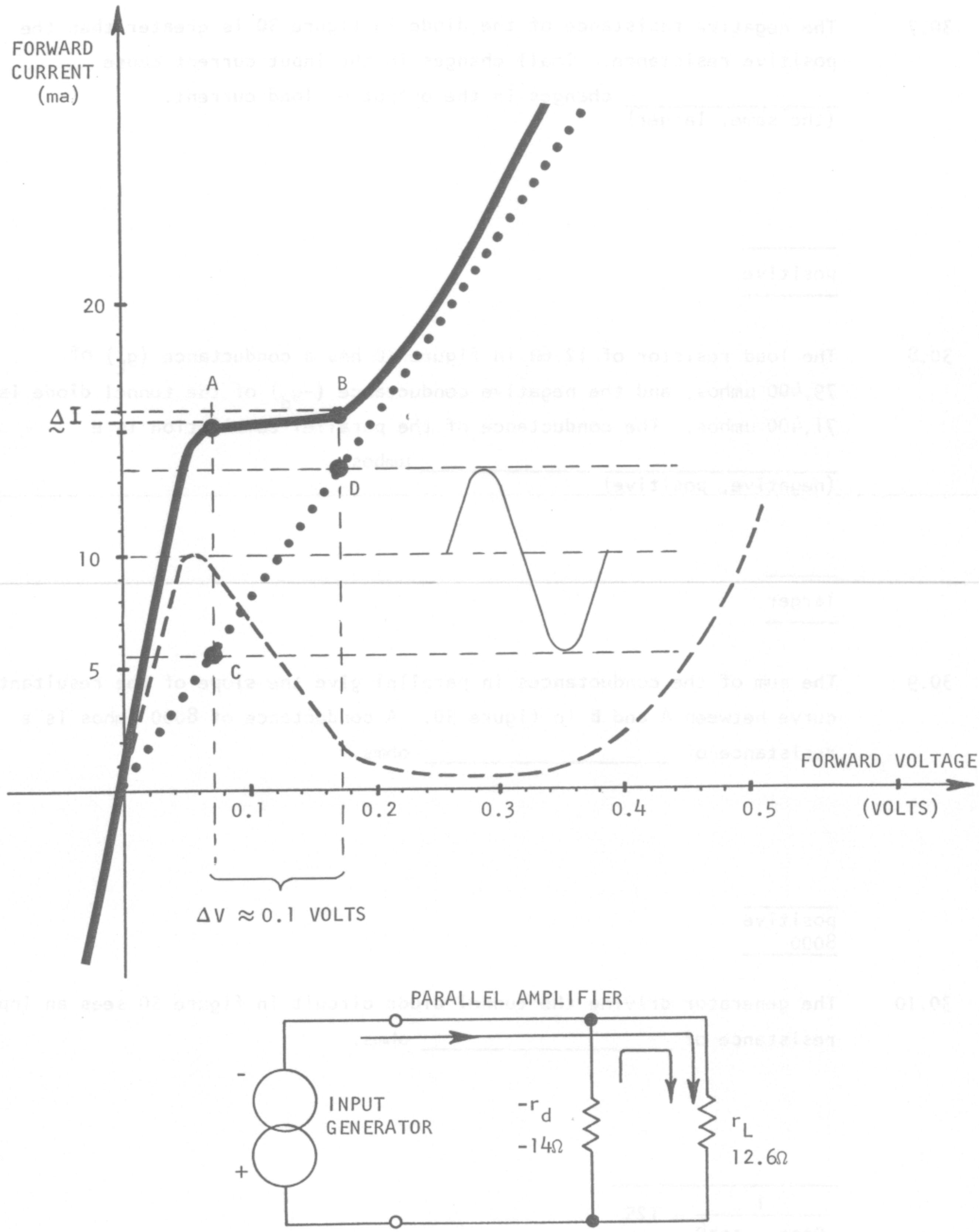

FORWARD CURRENT (ma)
20
10
5
A
B
C
D
ΔI
FORWARD VOLTAGE
0.1
0.2
0.3
0.4
0.5
(VOLTS)
ΔV ≈ 0.1 VOLTS
PARALLEL AMPLIFIER
INPUT GENERATOR
-
+
$-r_d$
-14Ω
r_L
12.6Ω

FIGURE 30

30.11 The input current is the change in input voltage divided by the input resistance. In figure 30, with an input voltage of $\Delta 0.1$ volts, the input current is ___________ ma.

125

30.12 The output current is measured between C and D on the resistor line in figure 30, and is _________ ma.

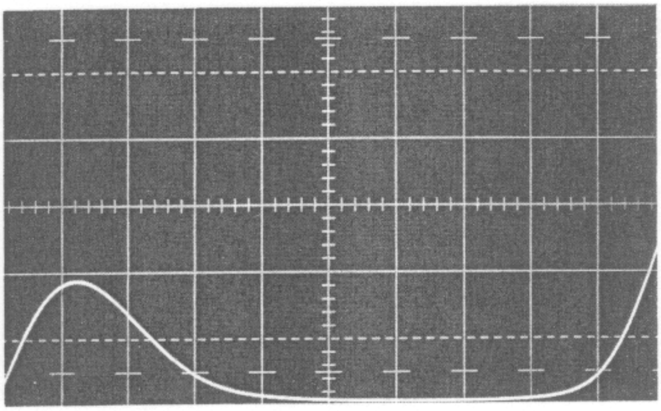
$\frac{100 \text{ mvolts}}{125\Omega} = 0.8$ ma

30.13 The current gain is found by dividing the output current by the input current, and in figure 30, the current gain is ____________.

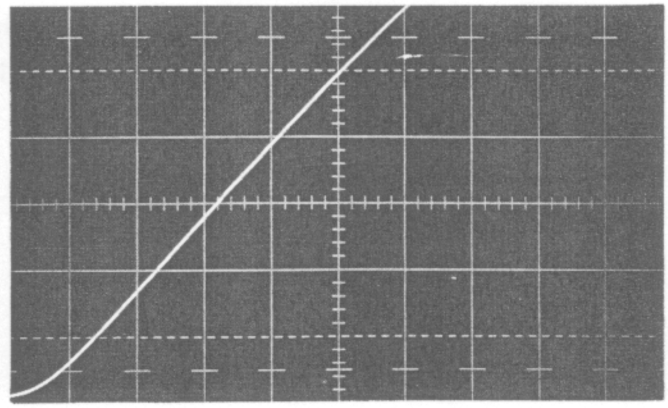
8

30.14 The current gain is essentially the load conductance divided by the input conductance. In figure 30, $\frac{g_L}{g_{in}} \approx$ ___________.

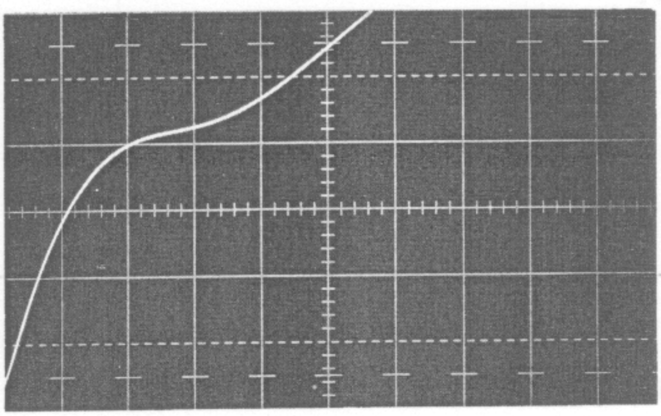
10



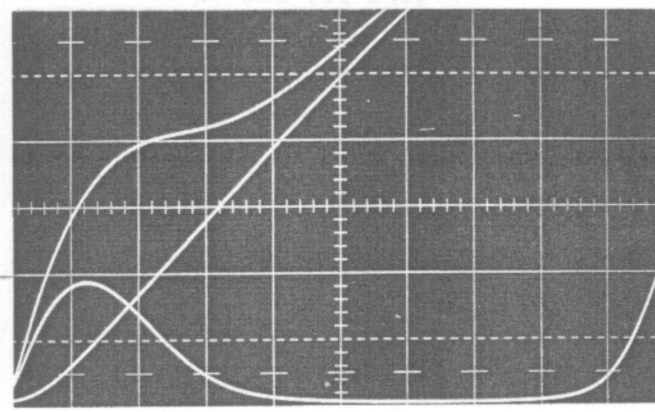
TUNNEL DIODE EI CURVE



RESISTOR EI CURVE



RESULTANT OF RESISTOR AND
TUNNEL DIODE IN PARALLEL



TRIPLE EXPOSURE COMPARING
THE THREE CURVES

TEST SET-UP: TEKTRONIX TYPE 547 OSCILLOSCOPE, TYPE "O" OPERATIONAL AMPLIFIER PLUG-IN WITH TUNNEL DIODE DRIVER ADAPTER* AND TYPE C-12 OSCILLOSCOPE CAMERA

* NON-PRODUCTION ITEM

NOTE: The non-linearity of the resistor EI characteristic at the start (left hand) side is due to using the oscilloscope sweep waveform to drive the adapter. The sweep starts below ground and a diode in the adapter disconnects during this period. The non-linearity at the end (right hand) of the resistor EI characteristic is due to limited current in the adapter power supply. The area of interest is linear, however.

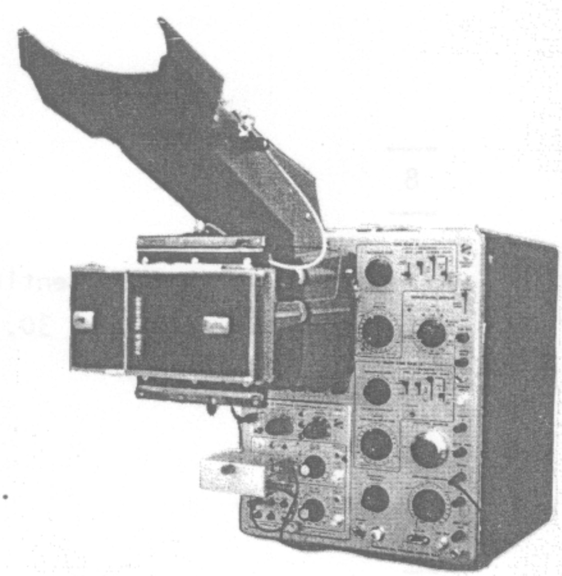


FIGURE 30A

30.15 Since the current gain is equal to the load conductance divided by the input conductance, the current gain can be predicted by the formula:

$$A_i = \frac{g_L}{g_{in}} \qquad \text{where } g_{in} = \underline{\hspace{4cm}}$$

$$\frac{79,400 \times 10^{-6}}{8,000 \times 10^{-6}} \approx 10$$

30.16 The tunnel diode breaks into oscillations when small amounts of inductance and/or capacitance are present. The layout for low frequency operation adds enough inductance and/or capacitance to cause the diode to ____________.

$g_L + (-g_d)$

30.17 The tunnel diode, as an amplifier, is limited to high frequency operation where the inductance and capacitance may be kept ________________.

oscillate

30.18 Figure 30A shows the test set-up used to obtain the information in figure 30. The resultant curve represents a ________________ (positive, negative) conductance.

small, minimum, low

30.19** 

A is the ________________ and B is the ______________ in the symbol shown for a ________________ diode. The parallel combination of positive and negative conductance must give a positive conductance resultant if the tunnel diode is to serve as an ______________, and the negative resistance of the tunnel diode must be ______________ (less, greater) than the positive resistance. Tunnel diode amplifiers are limited to high ________________________ operation so that the reactances may be kept to a minimum.

positive

30.20 END OF SET

cathode
anode
tunnel
amplifier
greater
frequency

31 The series tunnel diode amplifier must have a negative resistance ______________ than the total series positive resistance. The total
(less, greater)
possible current and voltage changes are limited by the ______________ resistance area of the tunnel diodes characteristic for both series and parallel amplifier configurations. The series amplifier offers ______________ gain, and the algebraic sum of the positive and nega-
(voltage, current)
tive resistances is the ______________ resistance of the amplifier circuit.

31.1 In order to serve as an amplifier, the tunnel diode must be biased in and operate in the negative resistance region of its characteristic. Maximum current change is limited between peak current and ______________ current.

greater
negative
voltage
input

31.2 Since the tunnel diode must remain in the negative resistance region to serve as an amplifier, maximum possible voltage change is limited between ______________ voltage and ______________ voltage points.

valley

31.3 Figure 31 is a set of curves for a series tunnel diode amplifier. The dashed curve is the tunnel diodes EI curve. The dotted line is the load resistors EI characteristic, and the solid curve is the series resultant curve and results from the algebraic ____________ of the series resistances.

peak
valley

31.4 The algebraic sum of the load resistor (r_L) and the negative resistance of the tunnel diode ($-r_d$) in figure 31 is ______________ ohms.

$$r_L + (-r_d) = 12.6\Omega + (-14\Omega) = ?$$

sum

31.5 The generator in figure 31 sees an input resistance of -1.4Ω. An input voltage change of 11.9 mvolts causes a current change of ____________ ma.

$$\frac{\Delta V}{r_{in}} = \frac{11.9 \text{ mvolts}}{-1.4\Omega} = ?$$

$$r_L + (-r_d) = 12.6\Omega + (-14\Omega) = -1.4\Omega$$

31.6 The 8.5ma change flows in the positive resistor (r_L) of 12.6 ohms and develops a voltage change of ______________ mvolts.

$$\Delta E = \Delta I \quad r_L = -8.5\text{ma } 12.6\Omega = ?$$

$$\frac{11.9 \text{ mvolts}}{-1.4\Omega} = -8.5\text{ma}$$

31.7 The voltage gain is found by dividing the output voltage by the input voltage, and in figure 31, the voltage gain is ________________.

-107.1

31.8 The voltage gain is essentially equal to the load resistance divided by the input resistance. In figure 31, $\frac{12.6\Omega}{-1.4\Omega}$ = ________________.

$\frac{107.1mv}{11.9mv} = -9$

31.9 Since input resistance is equal to the algebraic sum of the positive resistance and the diodes negative resistance $(r_L + (-r_d)$, the gain can be predicted by the formula:

$$A_v = \frac{r_L}{r_{in}} \quad \text{where } r_{in} = \_\_\_\_\_\_\_\_\_\_\_\_$$

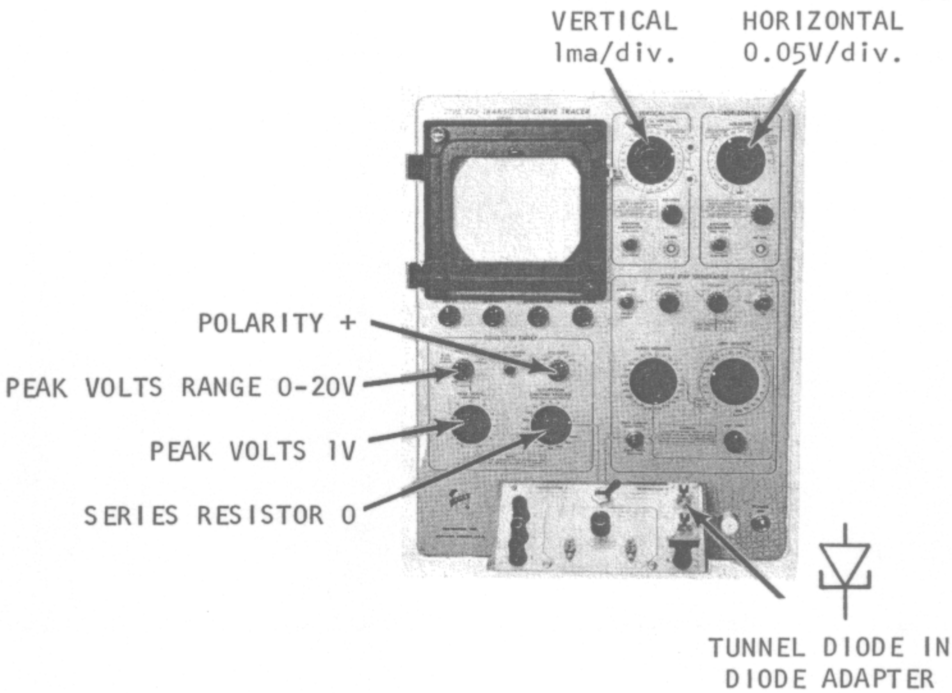
-9

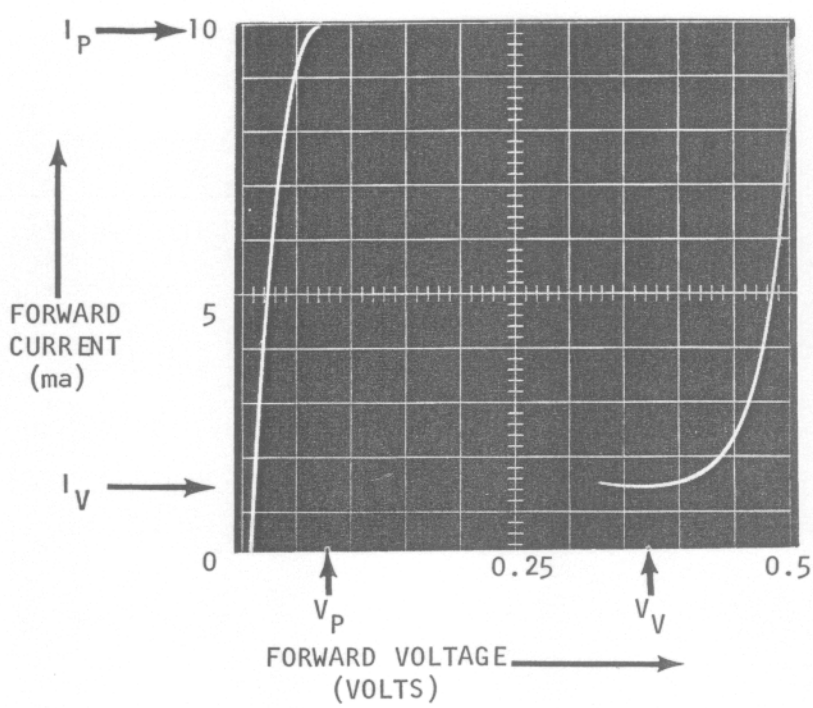
31.10** In order to serve as a series amplifier, the total series positive resistance must be ____________ (less, more) than the negative resistance of the tunnel diode. The amplifiers input resistance is equal to the algebraic ____________ of the series positive and negative resistances. The series tunnel diode amplifier gives ________________ (current, voltage) gain.

$r_L + (-r_d)$

31.11 END OF SET

less
sum
voltage





TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH DIODE ADAPTER. PHOTO ABOVE TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.

FIGURE 32

32 The negative resistance region cannot be seen in figure 32 because the tunnel diode is in the ________________ mode. The 575 does not give a true and complete display of the tunnel diode EI curve because of internal ________________ in the instrument. The tunnel diodes' negative resistance can be approximated from the display in figure 32 using the formula ______________________________. A variable ________________ can be placed in parallel with the tunnel diode and the 575 used to measure ________________ ________________.

32.1 The internal resistance of the Tektronix Type 575 Transistor-Curve Tracer is, in most cases, too large to allow observation of the negative conductance region of a tunnel diode. Because of the high internal resistance, the tunnel diode is forced to <u>switch</u> between its positive slopes.

switching

resistance

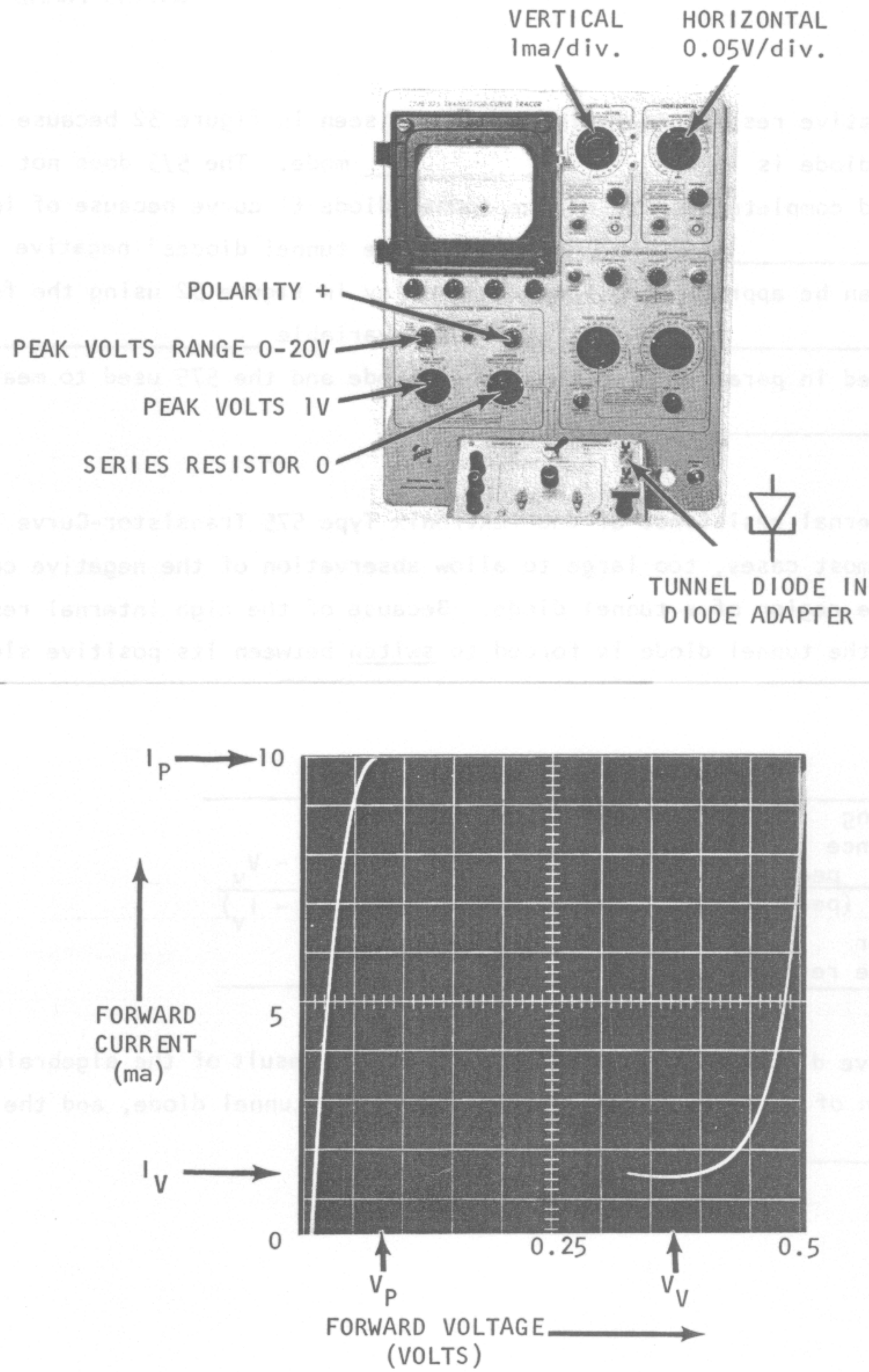
$$-r_d \approx \frac{\text{peak voltage - valley voltage}}{2\ (\text{peak current - valley current})} \approx \frac{V_p - V_v}{2\ (I_p - I_v)}$$

resistor

negative resistance

32.2 The curve displayed on the 575 is actually a result of the algebraic addition of the __________ resistance of the tunnel diode, and the __________ resistance in series.

no answer needed



TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH DIODE ADAPTER.
PHOTO ABOVE TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.

FIGURE 32

32.3 A good approximation of the negative resistance of the tunnel diode can be made by solving from the 575 display and then multiplying the calculated value by one half.

$$-r_d \approx \frac{V_p - V_v}{I_p - I_v} \times \underline{\hspace{3cm}}$$

negative
positive

32.4 The negative conductance formula can be found by taking the reciprocal of the negative resistance formula.

$$-g_d \approx \frac{1}{\frac{V_p - V_v}{I_p - I_v}\ \frac{1}{2}} \approx \frac{2\ (I_p - I_v)}{V_p - V_v}$$

0.5 or 1/2

32.5 The negative resistance of the tunnel diode in figure 32 is approximately ______________ ohms, and the negative conductance is approximately ______________ µmhos.

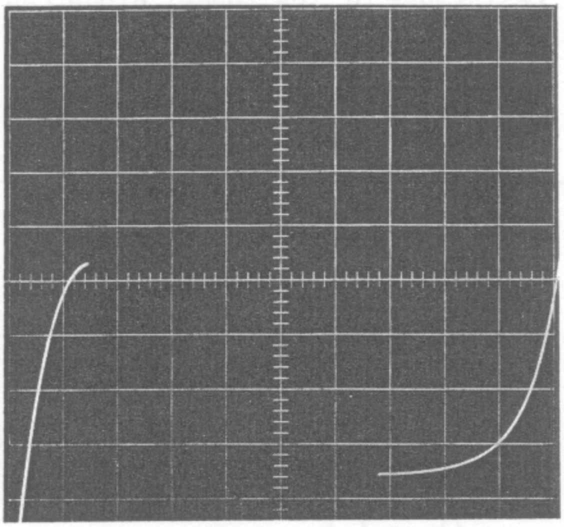
$$-r_d \approx \frac{V_p - V_v}{2(I_p - I_v)} \qquad -g_d \approx \frac{2(I_p - I_v)}{V_p - V_v}.$$

no answer needed

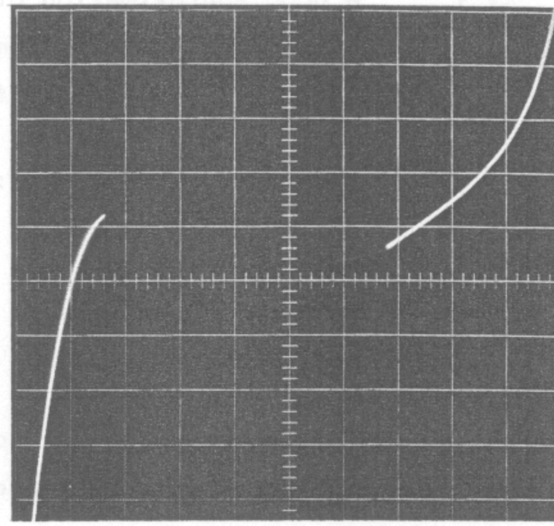
32.6 The negative resistance can be measured more accurately by adding a parallel variable resistor to the tunnel diode in the test set-up in figure 32A.

$$-r_d \approx \frac{V_p - V_v}{2\ (I_p - I_v)} \approx \frac{0.075V - 0.375}{2\ (10ma - 1.5ma)} \approx -17.6\Omega$$

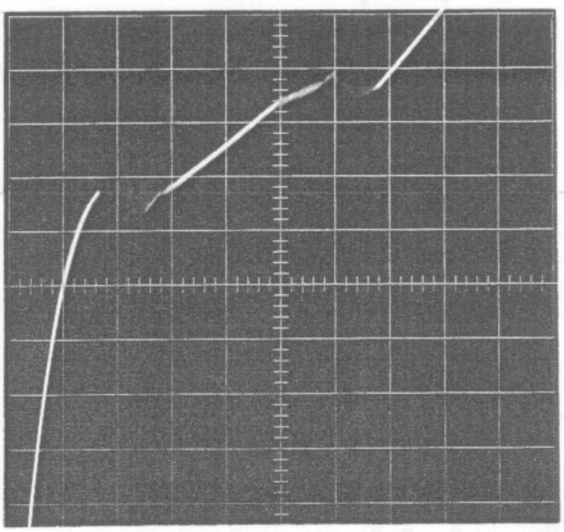
$$-g_d \approx \frac{2\ (I_p - I_v)}{V_p - V_v} \approx \frac{2\ (10ma - 1.5ma)}{0.075V - 0.375V} \approx -56{,}666\ \mu mhos$$



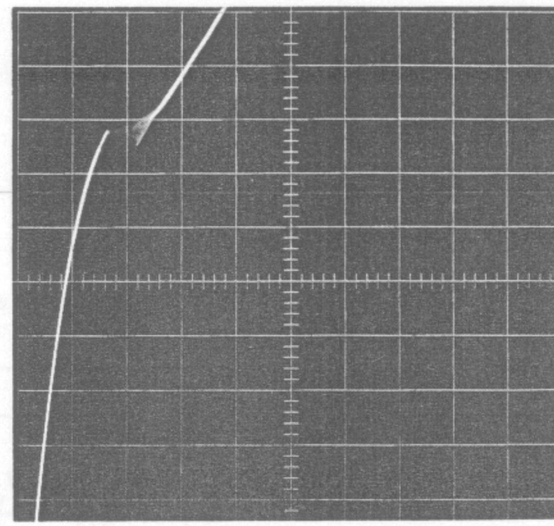
1. r_L VERY MUCH GREATER THAN $-r_d$



2. r_L MUCH GREATER THAN $-r_d$

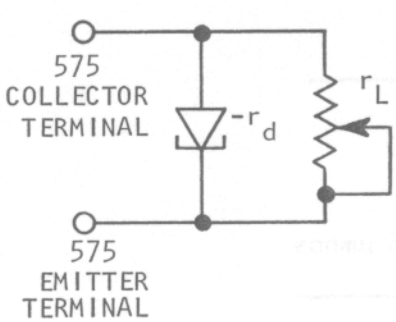


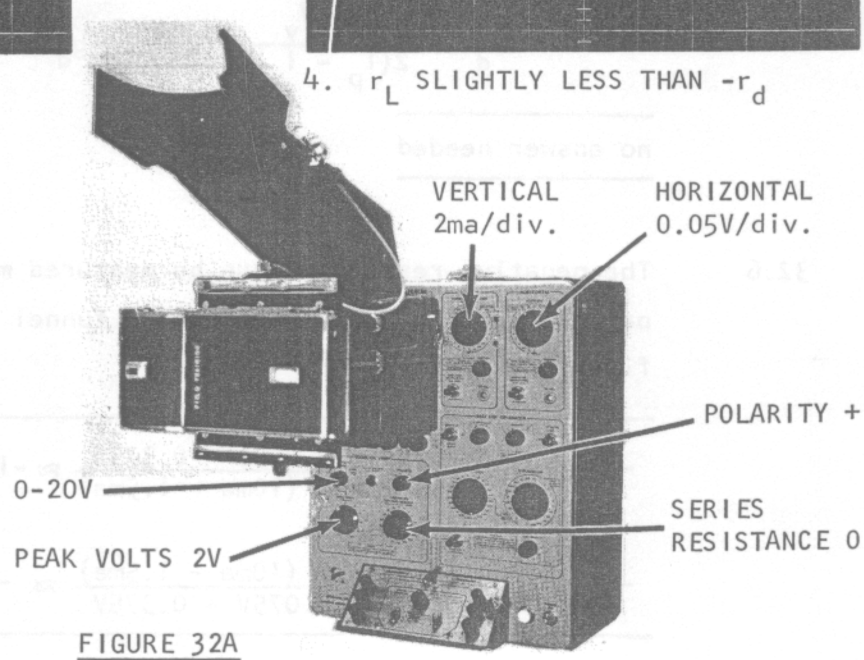
3. r_L GREATER THAN $-r_d$



4. r_L SLIGHTLY LESS THAN $-r_d$

<u>TEST SET-UP</u>: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH TYPE C-12 CAMERA AND CIRCUIT SHOWN BELOW.





<u>FIGURE 32A</u>

32.7 The parallel resistance is started at its maximum value so that it has very little effect, as shown in figure 32A1.

no answer needed

32.8 As the resistance of the variable resistor is decreased, the algebraic sum of the positive and negative conductances becomes less ______ as shown in figure 32A2.
(negative, positive)

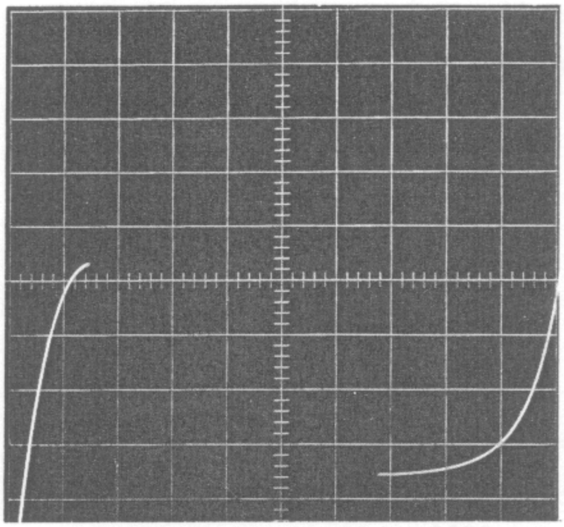
no answer needed

32.9 As the positive resistance value approaches the diodes' negative resistance value, as shown in figure 32A3, the diode is still switching between the first and second positive slopes, but some oscillation is apparent in the negative resistance region.

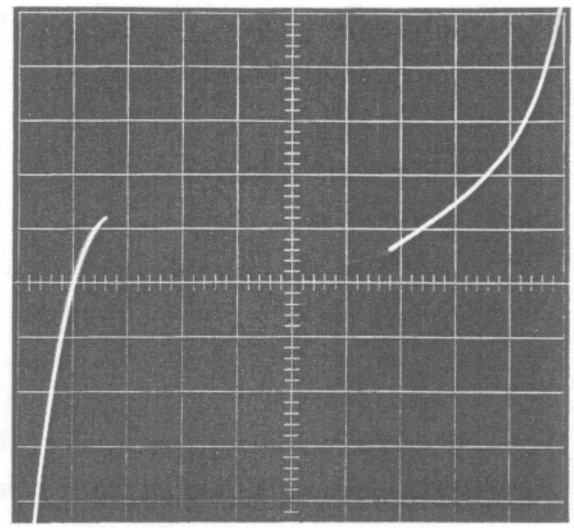
negative

32.10 As the positive resistance becomes less than the negative resistance, the diode will stop switching to the second positive slope, as shown in figure 32A4. The resultant conductance is now ______ at all points on the curve.
(positive, negative)

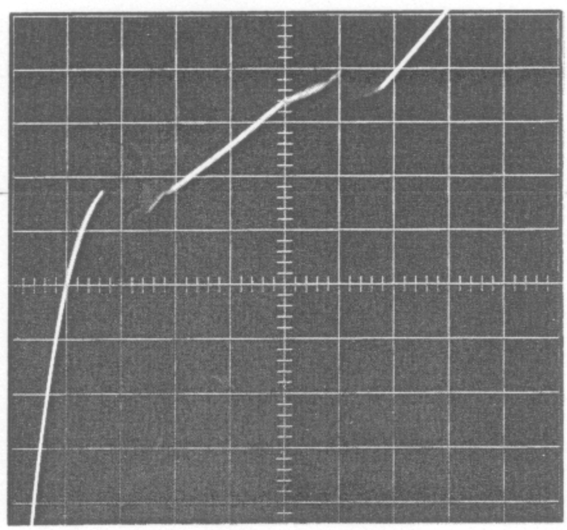
no answer needed



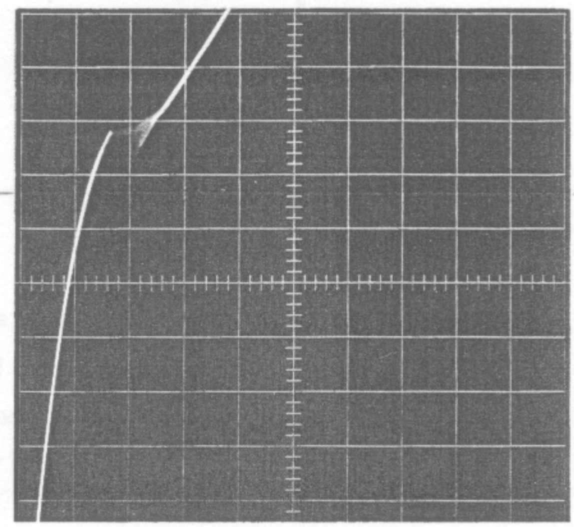
1. r_L VERY MUCH GREATER THAN $-r_d$



2. r_L MUCH GREATER THAN $-r_d$

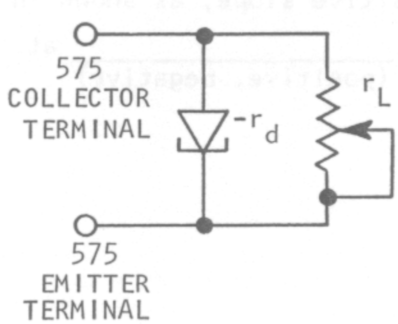


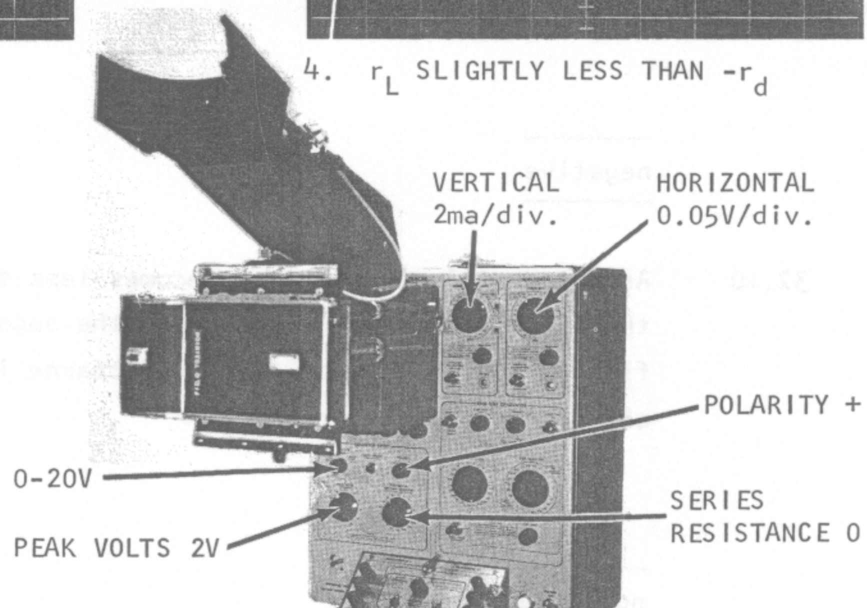
3. r_L GREATER THAN $-r_d$



4. r_L SLIGHTLY LESS THAN $-r_d$

<u>TEST SET-UP</u>: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER WITH TYPE C-12 CAMERA AND CIRCUIT SHOWN BELOW.





<u>FIGURE 32A</u>

32.11 The diode is removed from the circuit and the resistance of the variable resistor measured. The value measured is slightly less than the __________ __________ of the tunnel diode.

positive

32.12 The value measured for the tunnel diode used in figure 32 and 32A was 14 ohms. The value approximated for this tunnel diode was 17.6 ohms.

negative resistance

32.13** The 575 internal resistance is high enough in most cases to cause a tunnel diode to switch between the __________ slopes, and the EI curve seen is a resultant and not a true representation of the diodes characteristics. The __________ resistance region cannot be seen at all. The negative conductance can be approximated by the formula __________, or a variable resistor can be placed in __________ with the tunnel diode and used as an aid in measuring negative resistance.

no answer needed

32.14 END OF SET

positive
negative

$$-g = \frac{2\,(I_p - I_v)}{V_p - V_v}$$

parallel

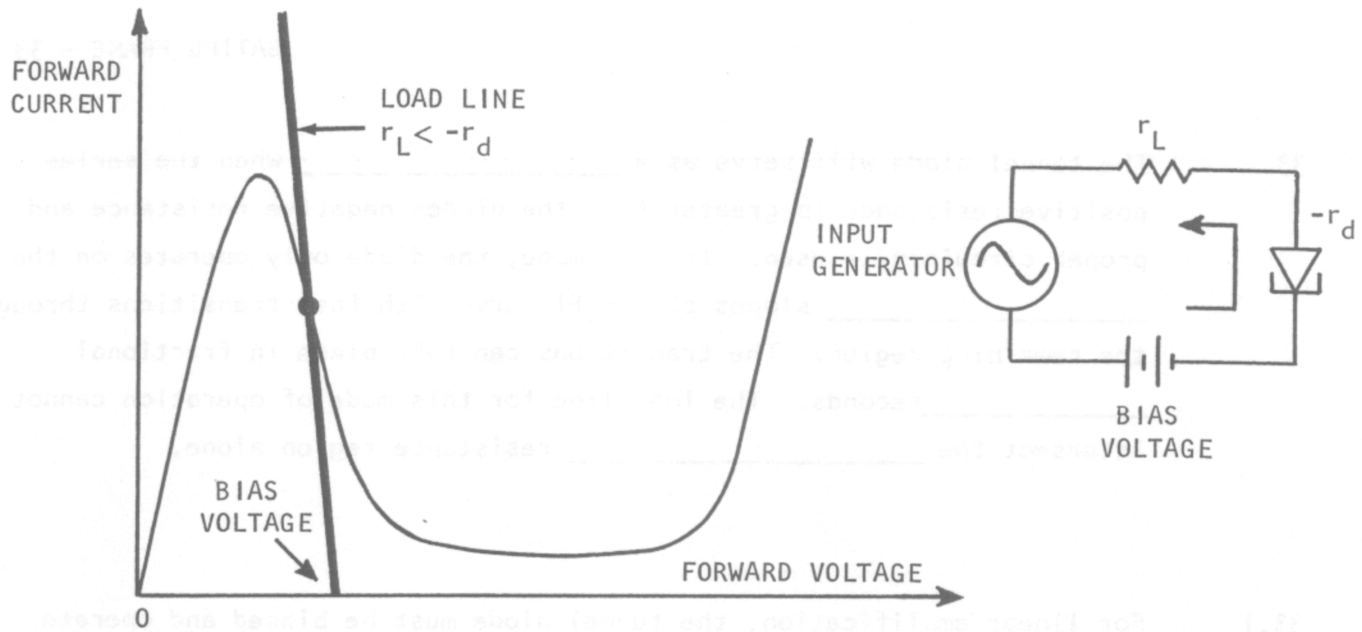
33 The tunnel diode will serve as a ____________________ when the series positive resistance is greater than the diodes negative resistance and proper circuitry is used. In this mode, the diode only operates on the ____________________ slopes of its EI curve with fast transitions through the remaining region. The transitions can take place in fractional ______________seconds. The load line for this mode of operation cannot intersect the ______________________ resistance region alone.

33.1 For linear amplification, the tunnel diode must be biased and operate <u>only</u> in the negative resistance region of its characteristic. This requires that the total series positive resistance be ____________ (less, more) than the diodes ____________________ resistance.

switch
positive
nano
negative

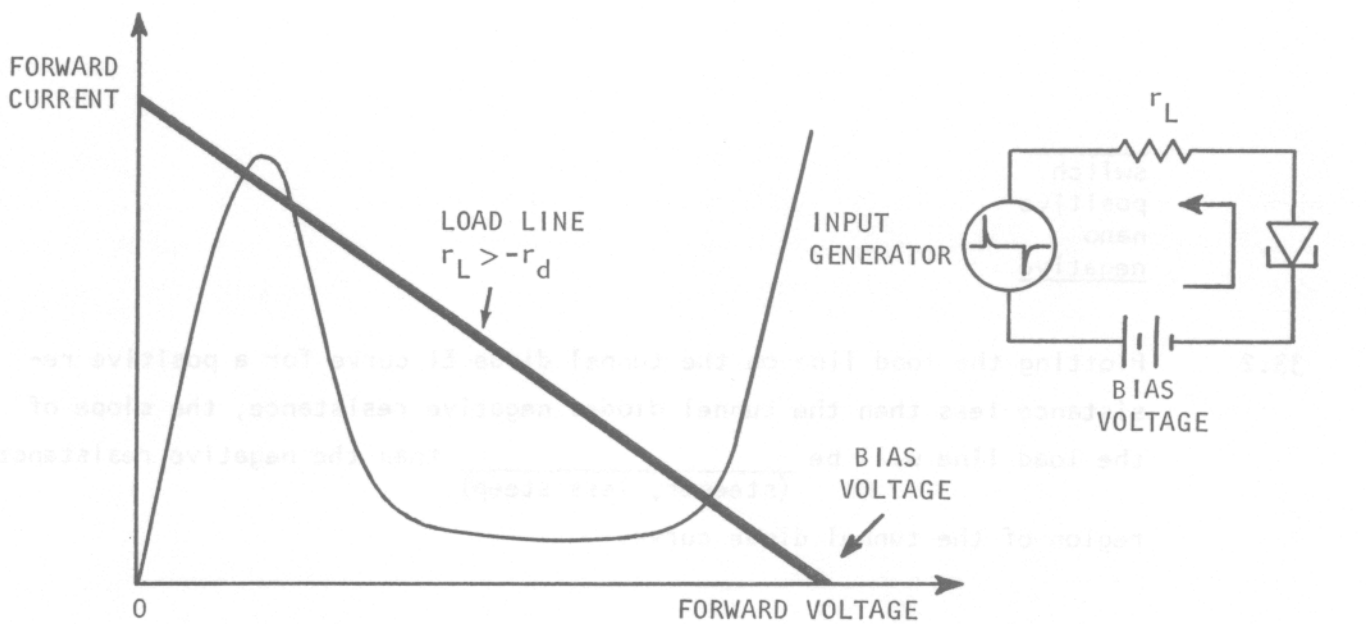
33.2 Plotting the load line on the tunnel diode EI curve for a positive resistance less than the tunnel diodes negative resistance, the slope of the load line will be ____________________ (steeper, less steep) than the negative resistance region of the tunnel diode curve.

less
negative



STABLE MODE: AMPLIFIER

FIGURE 33A



UNSTABLE MODE: SWITCHING

FIGURE 33B

33.3 For linear amplifier action, the load line must intersect the ________ (negative, positive) resistance portion of the tunnel diode EI curve.

steeper

33.4 The diagram in figure 33A shows a load line and proper biasing for amplifier operation. The load line intersects the ________ resistance region.

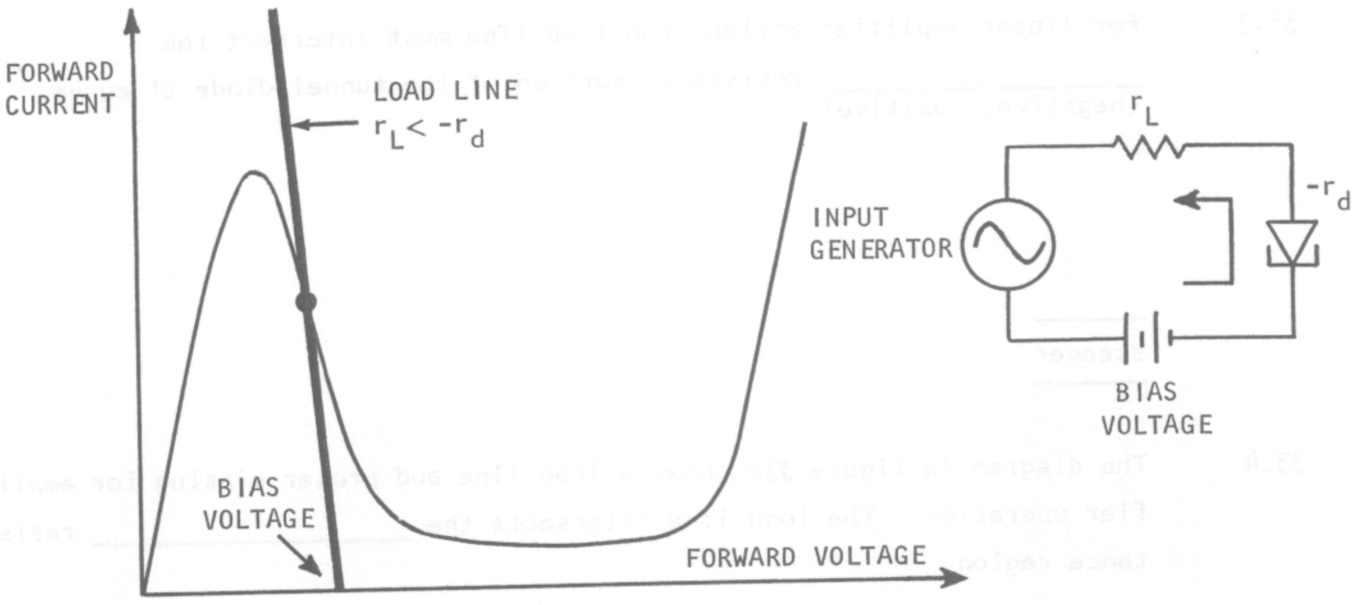
negative

33.5 The diagram in figure 33B has a load line with a slope that is not as steep as the negative resistance region. It is not possible for this load line to intersect the negative resistance region without also intersecting the ________ resistance region.

negative

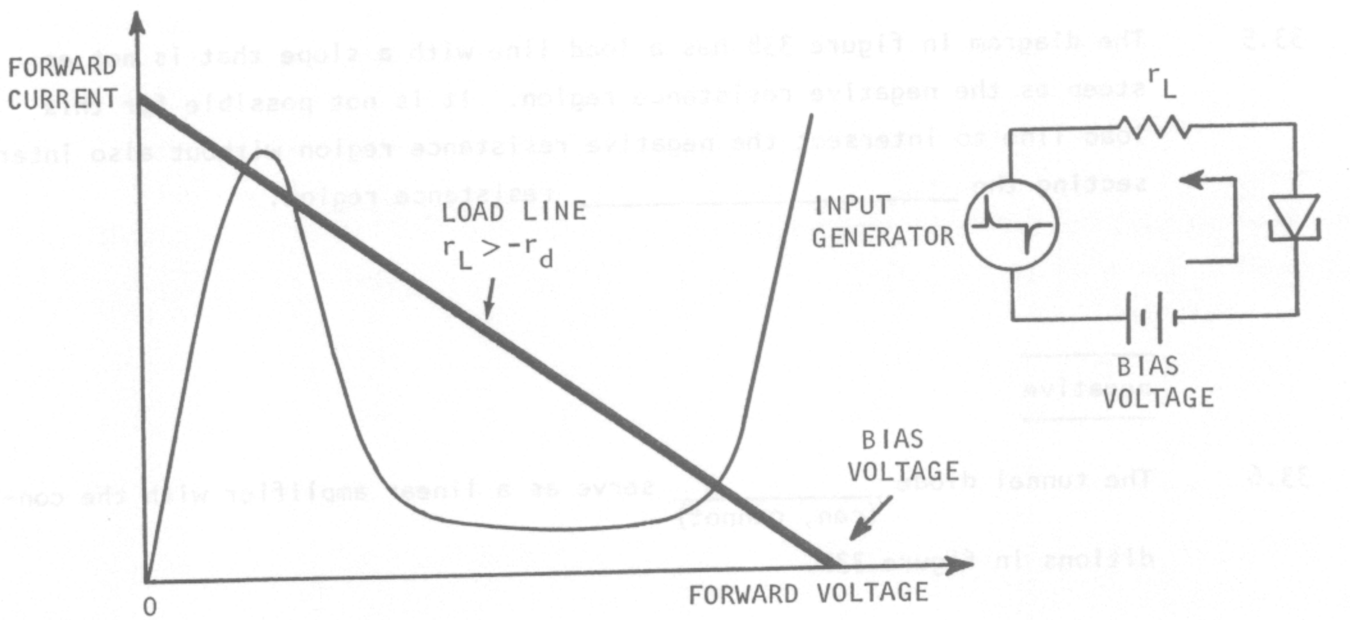
33.6 The tunnel diode ________ (can, cannot) serve as a linear amplifier with the conditions in figure 33B.

positive



STABLE MODE: AMPLIFIER

FIGURE 33A



UNSTABLE MODE: SWITCHING

FIGURE 33B

33.7 If the series positive resistance is greater than the tunnel diodes negative resistance, it cannot serve as a linear ______________________.

cannot

33.8 With the conditions in the diagram in figure 33B, the diode can rest on the first or second ________________________ slope, but not in the ____________________ resistance region.

amplifier

33.9 If forced beyond the first positive slope, the diode will switch rapidly to the second ______________________ slope with the load line in figure 33B.

positive
negative

33.10 With a series positive resistance greater than the tunnel diodes negative resistance, the tunnel diode (when driven by an appropriate source) will ______________________ between the _________________ slopes of its EI curve.

positive

33.11 The switching time between the positive slopes can occur in a fraction of a nanosecond when the tunnel diode is used in proper circuitry.

switch
positive

33.12 Very fast switching times can be accomplished with a tunnel diode with the total positive series resistance is ______________ (greater, less) than the diode's negative resistance.

no answer needed

33.13** Since the tunnel diode switch has a load line that is not as steep as the negative resistance region of the tunnel diode EI curve, it cannot intersect the negative resistance region without also intersecting the ____________________ resistance region. The tunnel diode can switch in fractional _____________ seconds.

greater

33.14 END OF SET

positi ve
nano

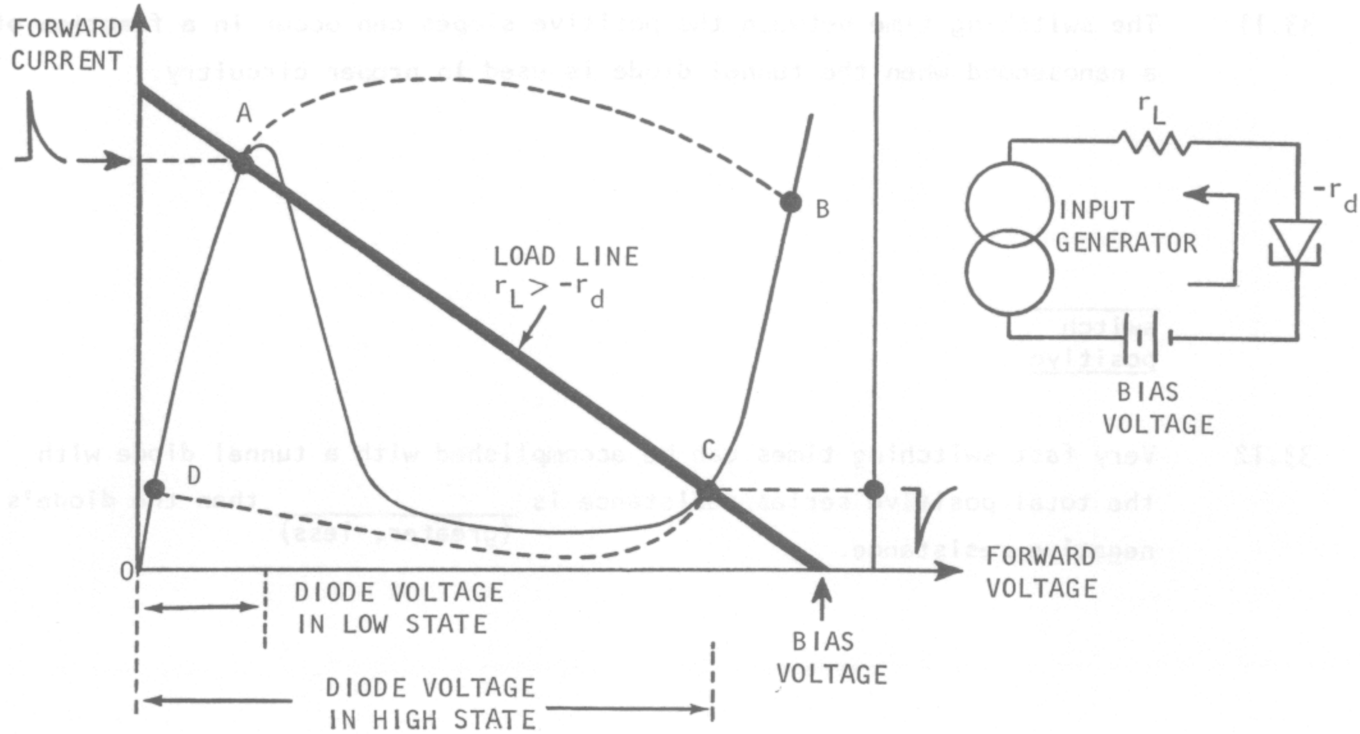


FIGURE 34A

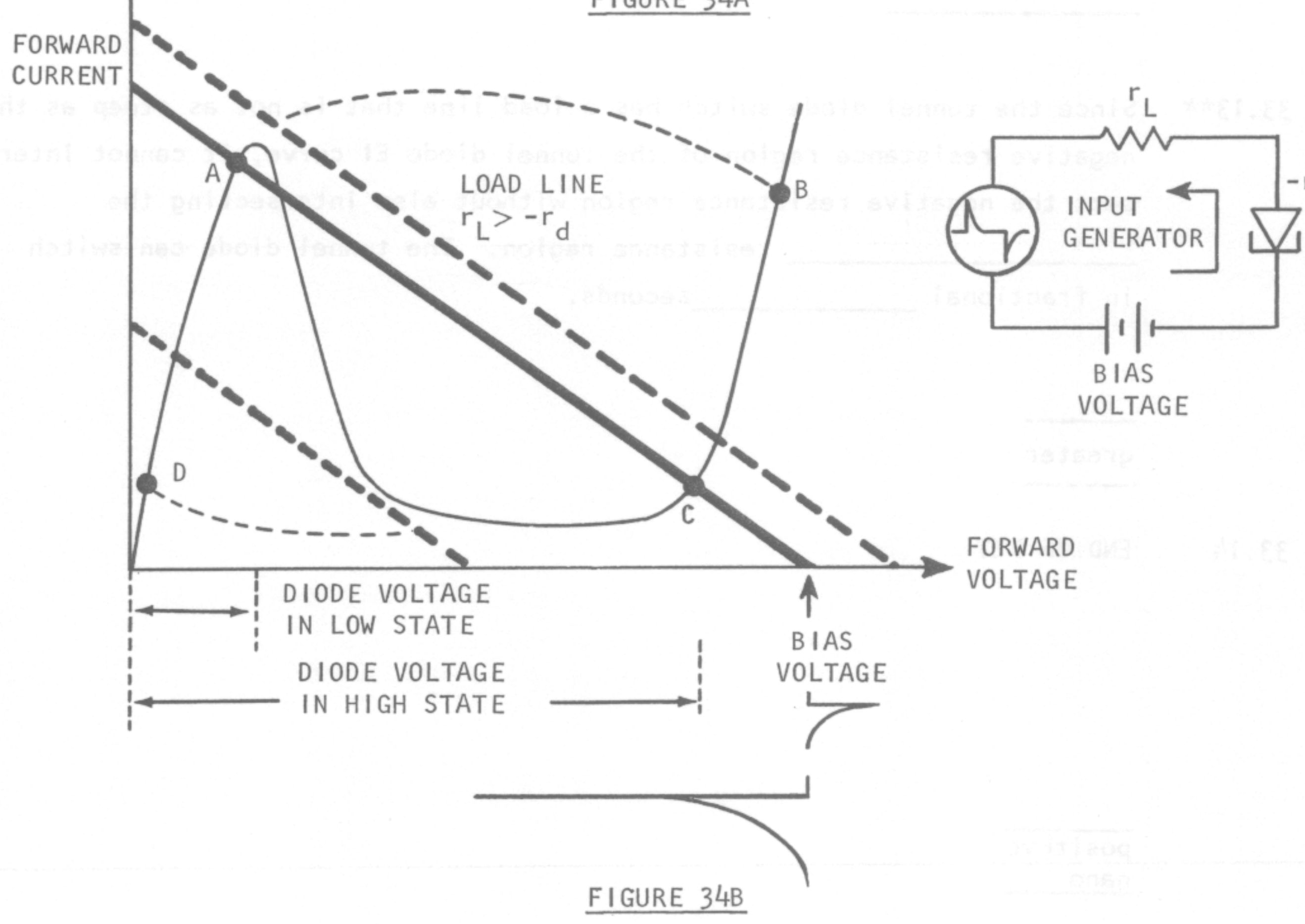


FIGURE 34B

34 The tunnel diode in figure 34A is a _______________ driven, __________-stable switch. Figure 34B is a ___________________ driven, __________-stable switch. When the input generator in figure 34A exceeds the _____________ ________________ of the tunnel diode, it switches to its high state and, when the input generator reduces below _______________ ___________________, the tunnel diode switches to its low state. When the input generator in figure 34B moves the load line past _____________ voltage, the tunnel diode switches to its high state and, when the load line is moved below ___________________ voltage, the tunnel diode switches back to its low state.

current
bi
voltage
bi
peak current
valley current
peak
valley

34.1 In figure 34A, the load line intersects the tunnel diode curve at #_____ points, and the tunnel diode can rest at points A or C. The series positive resistance is _______________ (greater, less) than the diodes negative resistance.

3
greater

34.2 With the tunnel diode resting at point A in figure 34A, the greater part of the supply voltage is across the ____________________ (load resistor, diode).

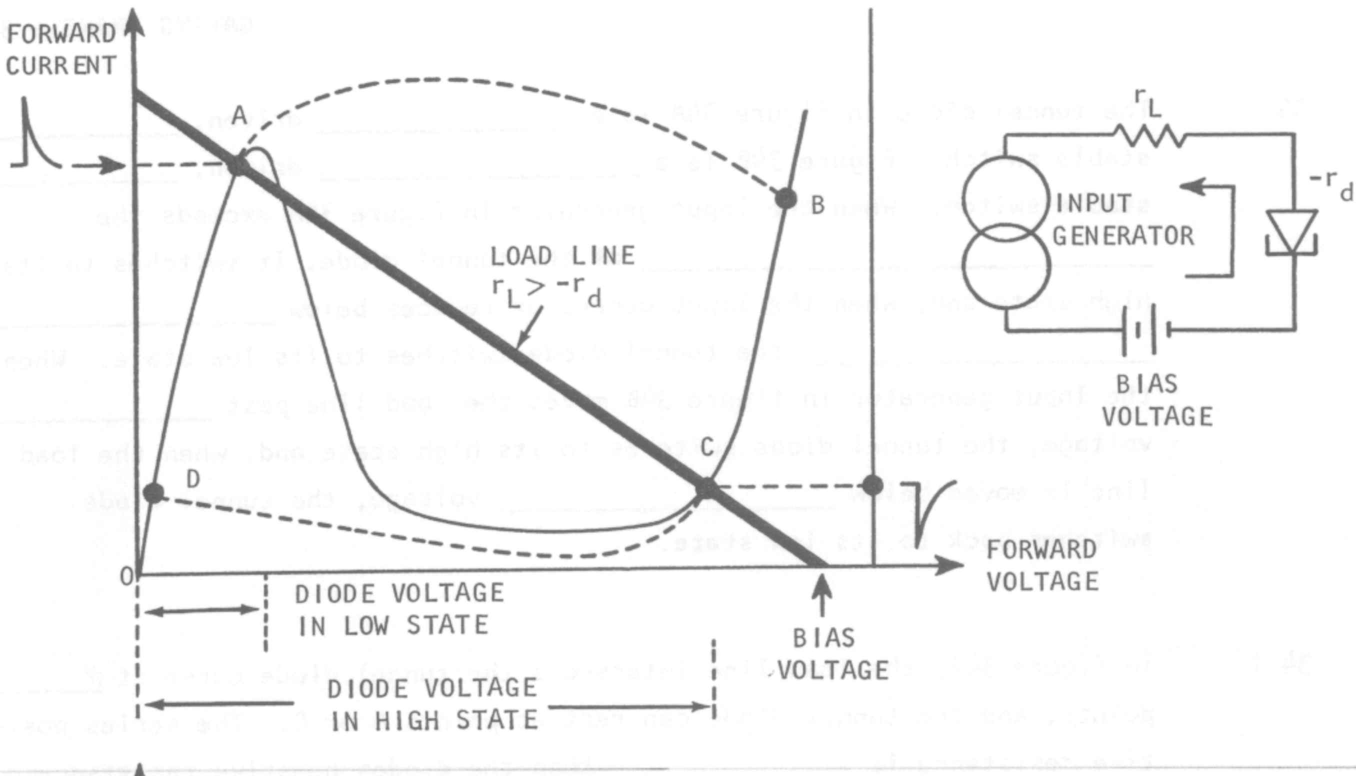


FIGURE 34A

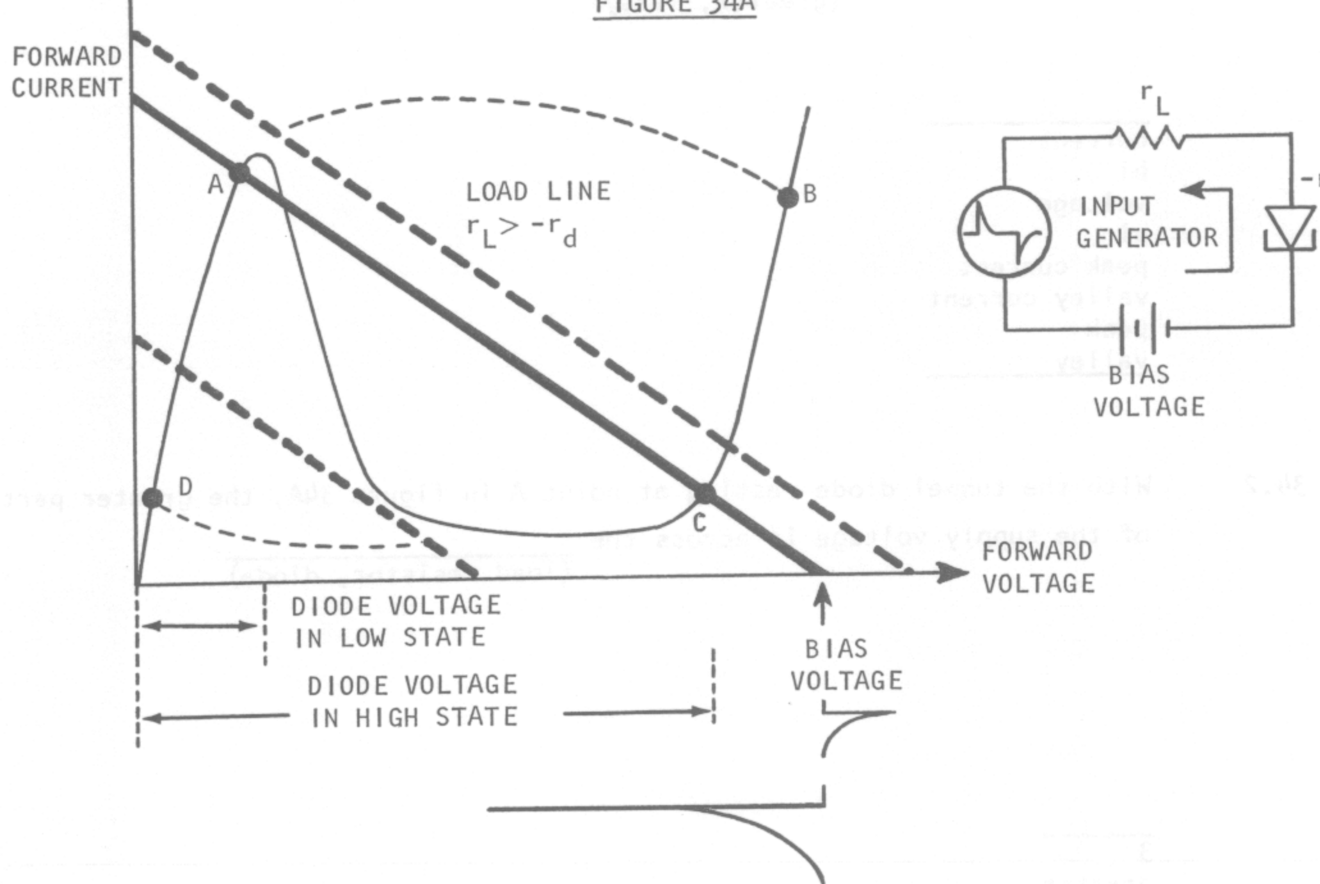


FIGURE 34B

34.3 If the input generator in figure 34A tries to increase the current beyond the diode's peak current, the tunnel diode will switch rapidly to somewhere near point B and then rest at point _________ on the diode curve.

load resistor

34.4 Increasing the diode's current beyond peak current with the load line in figure 34A will cause the tunnel diode to switch from its ____________ state to its ________________ state.

C

34.5 The tunnel diode in figure 34A is a current driven switch and, when in its high state, the majority of the supply voltage is across the ________________.
(diode, load resistor)

low
high

34.6 With the diode in figure 34A in its high state (resting at point C), the input generator must reduce the current below ____________ current to cause it to switch back to its low state.

diode

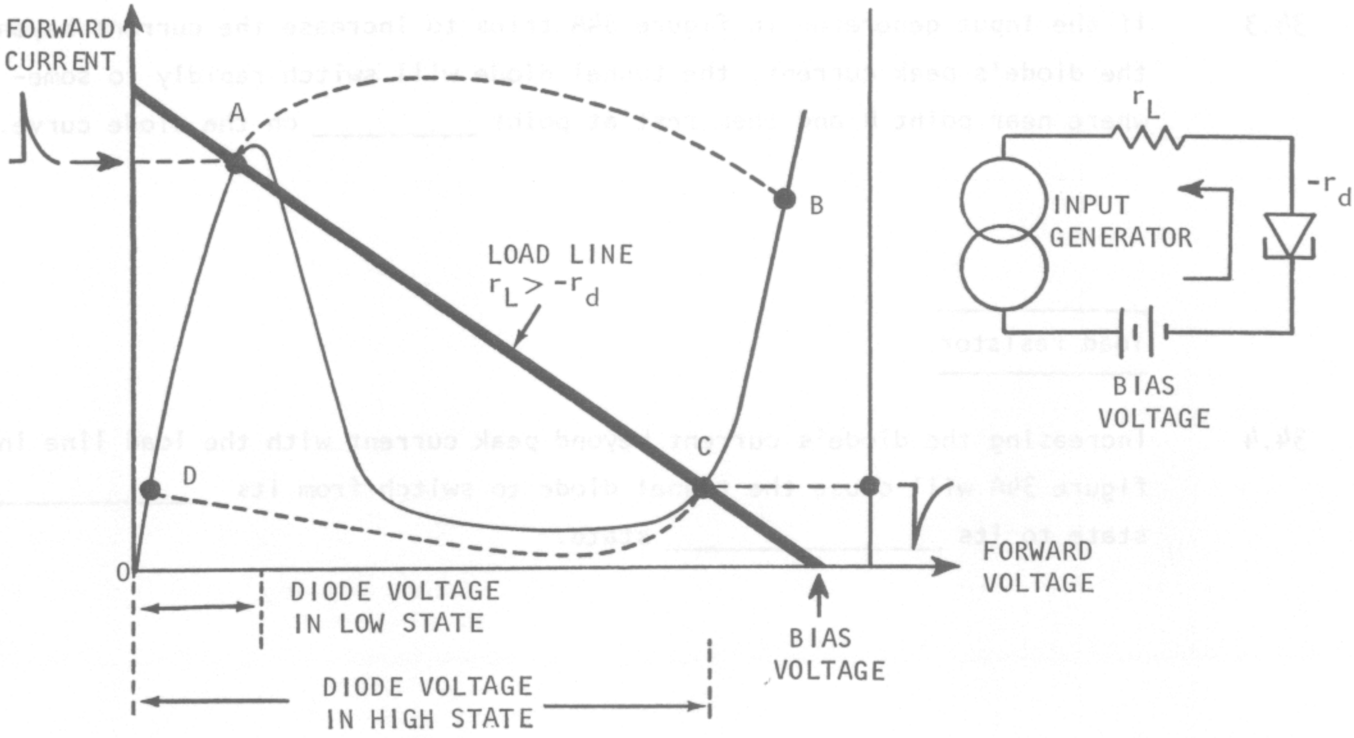


FIGURE 34A

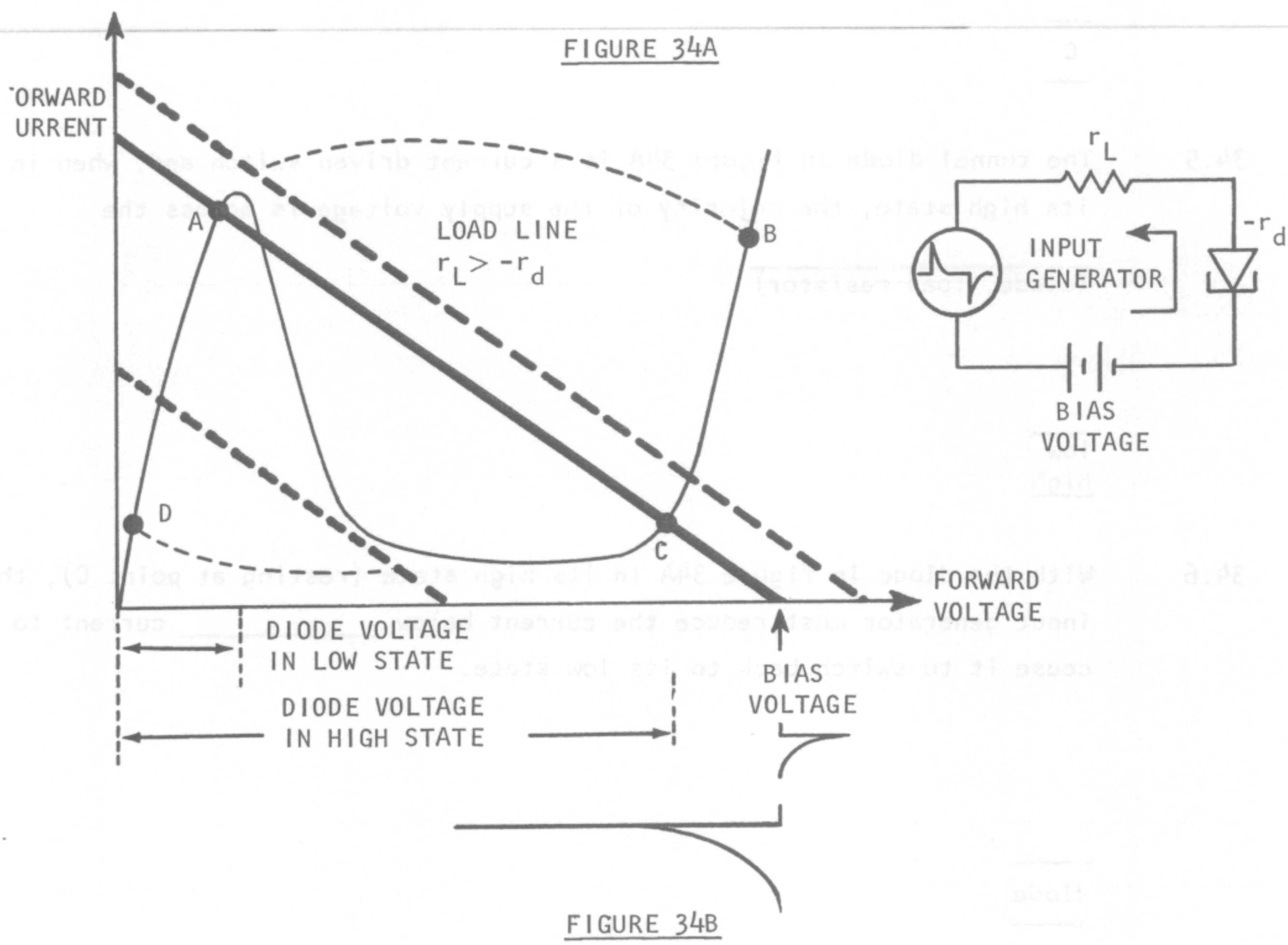


FIGURE 34B

34.7 The tunnel diode in figure 34A is a bi-stable, current driven switch. It is driven by current changes and has ______________ stable states.

valley

34.8 Figure 34B is a voltage driven, bi-stable switch in that it is driven by ______________ changes and has ______________ stable states.

two

34.9 With the tunnel diode in figure 34B resting at point A, the majority of the supply voltage is across the ____________________.
(diode, load resistor)

voltage
two

34.10 If the input generator increases the supply voltage, as shown in figure 34B, the load line (as shown by the dotted line) no longer intersects the first positive slope, and the tunnel diode must ______________________.

load resistor

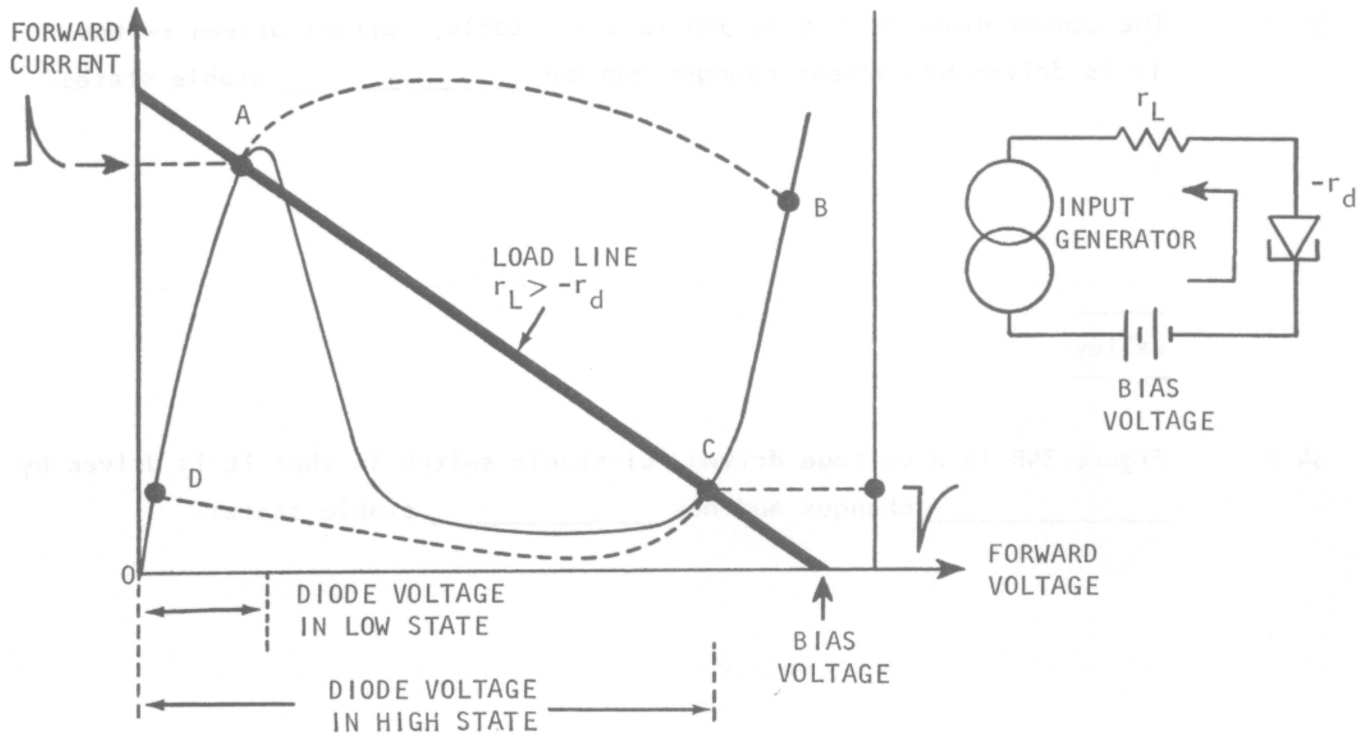


FIGURE 34A

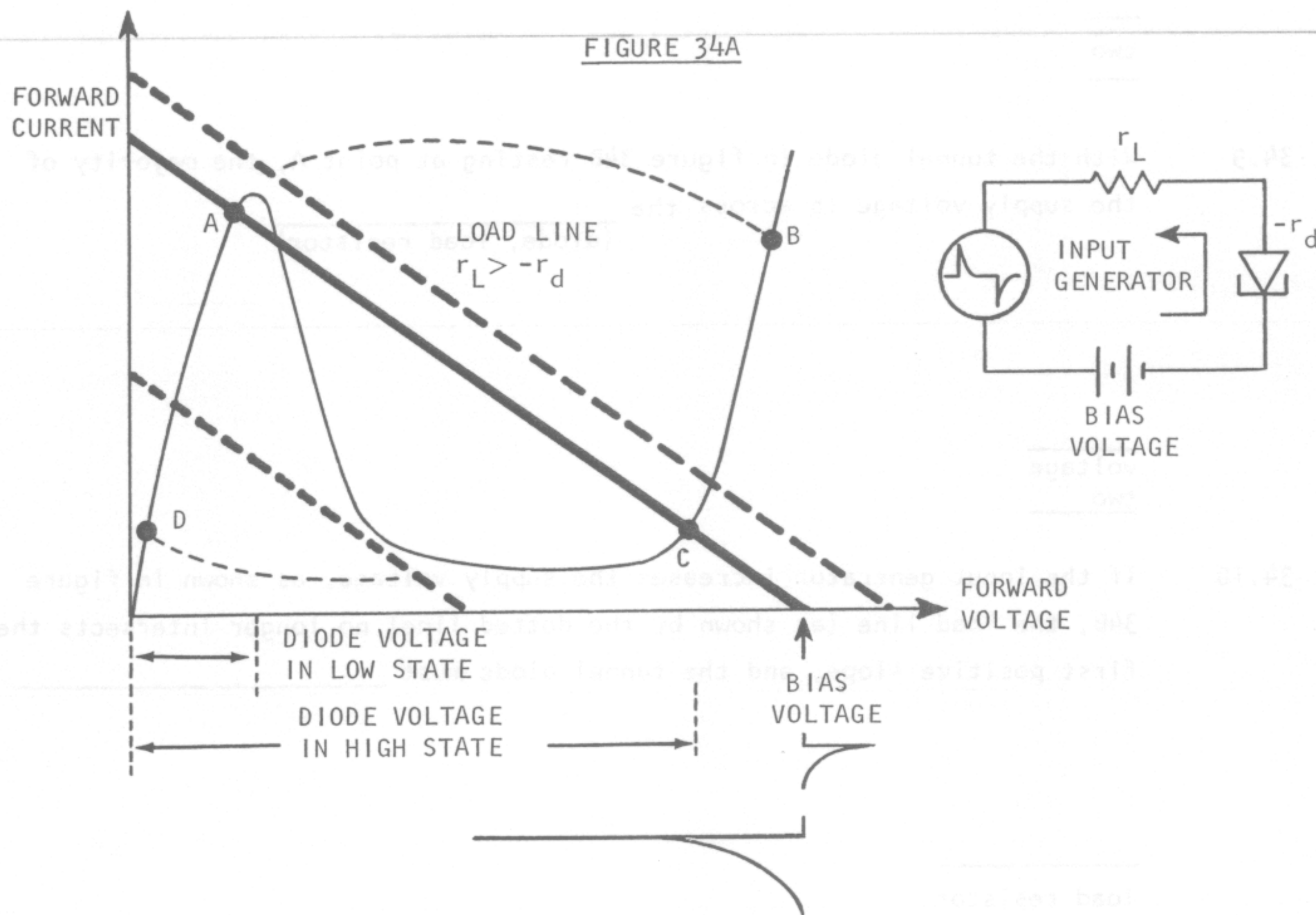


FIGURE 34B

34.11 The diode switched to somewhere near point B and then rests at point C in figure 34B. In this state, the majority of the supply voltage is across the ______________________.
(diode, load resistor)

switch

34.12 With the tunnel diode resting at point C, if the input generator reduces the supply voltage until the load line no longer intersects the second positive slope (as shown by the dashed line in figure 34B), the tunnel diode switches to its _______________ state.

diode

34.13 The tunnel diode initially switches to a point near point D in figure 34B when switched from its high to its low state. It then rests at point A again. The driving generator must move the load line below the ___________________ voltage to switch the diode from its high to its low state.

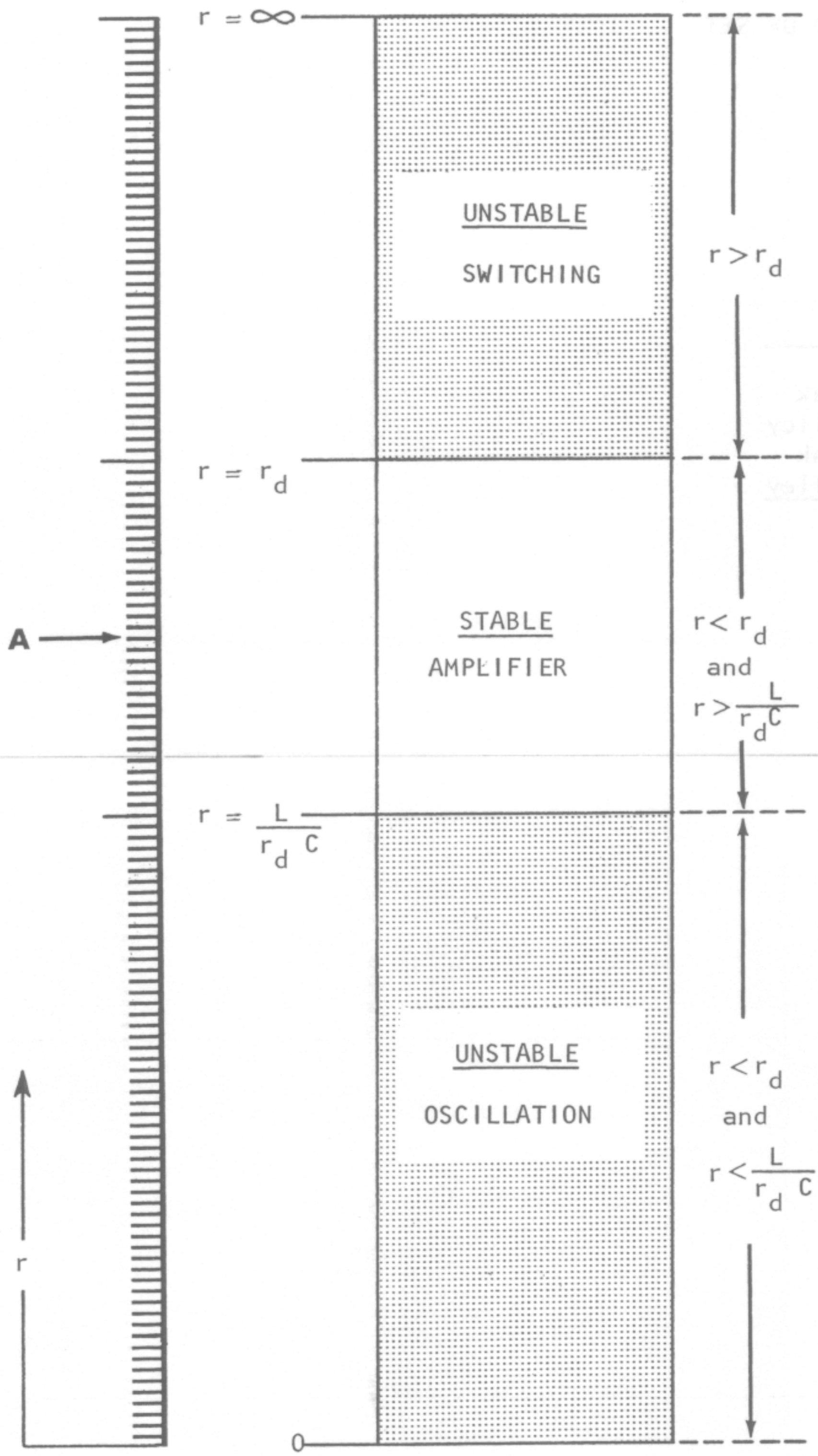
low

34.14** The tunnel diode switch can be current or voltage driven and serve as a _________-stable switch. When current driven, the switching levels are the ___________________ and ____________________ current levels. When voltage driven, the switching levels are the ______________________ and ______________________ voltage levels.

valley

34.15 END OF SET

bi
peak
valley
peak
valley



r = TOTAL CIRCUIT POSITIVE RESISTANCE
r_d = ABSOLUTE VALUE OF TUNNEL DIODE NEGATIVE RESISTANCE
L = TOTAL INDUCTANCE
C = TOTAL CAPACITANCE

FIGURE 35

35 With a value of total positive resistance (r) equal to A in figure 35, the tunnel diode circuit will operate in the ______________ mode and can be used as an ________________. The total positive resistance (r) is ______________ than the ratio of total inductance (L) to the product of the absolute value of negative resistance (r_d), and the total capacitance (C). Tunnel diode amplifier operation requires a __________ (high, low) power supply resistance.

35.1 Using the graph in figure 35, a value of r greater than r_d results in the tunnel diode operating in the ________________ mode.

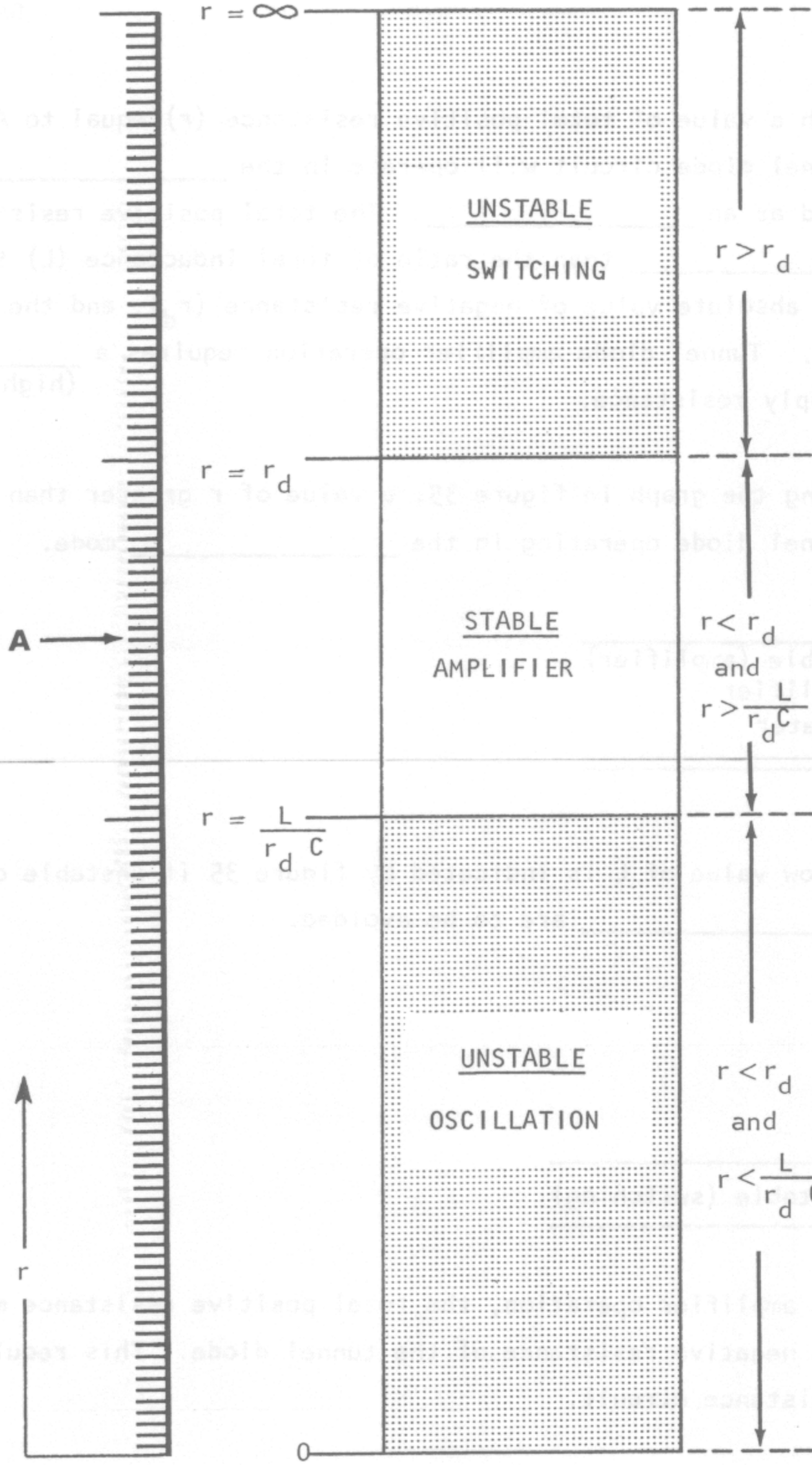
stable (amplifier)
amplifier
greater
low

35.2 A low value of L is indicated by figure 35 if unstable operation and _________________ are to be avoided.

unstable (switching)

35.3 For amplifier operation, the total positive resistance must be less than the negative resistance of the tunnel diode. This requires a __________ resistance circuit.

oscillations



r = TOTAL CIRCUIT POSITIVE RESISTANCE
r_d = ABSOLUTE VALUE OF TUNNEL DIODE NEGATIVE RESISTANCE
L = TOTAL INDUCTANCE
C = TOTAL CAPACITANCE

FIGURE 35

4 Tunnel diodes have values of negative resistances ranging from a few ohms to several hundred ohms. The bias power supply used must have a low internal ______________ when biasing a tunnel diode amplifier.

---

low

---

5 Referring to figure 35, if it is desired for the tunnel diode to oscillate, the positive resistance must be less than ________________ and ________________.

---

resistance

.6 Figure 35 outlines the stability requirements for all modes of operation. The stability requirements for linear amplifier operation are

__________ $< r <$ __________.

---

r_d

$\frac{L}{r_d C}$

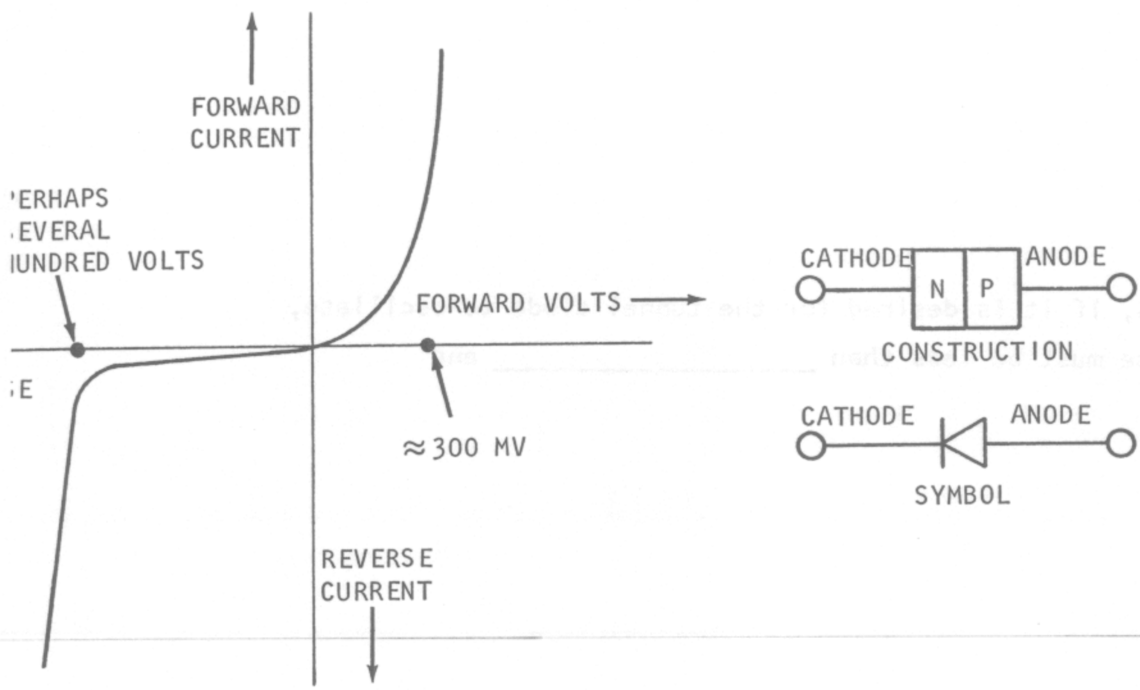
.7** The tunnel diode will oscillate when __________ $<$ ______________ and

____________ $<$ ____________.

$\frac{L}{r_d C} < r < r_d$

COMPARING A CONVENTIONAL AND A BACKWARD GERMANIUM DIODE

CONVENTIONAL DIODE



BACKWARD DIODE

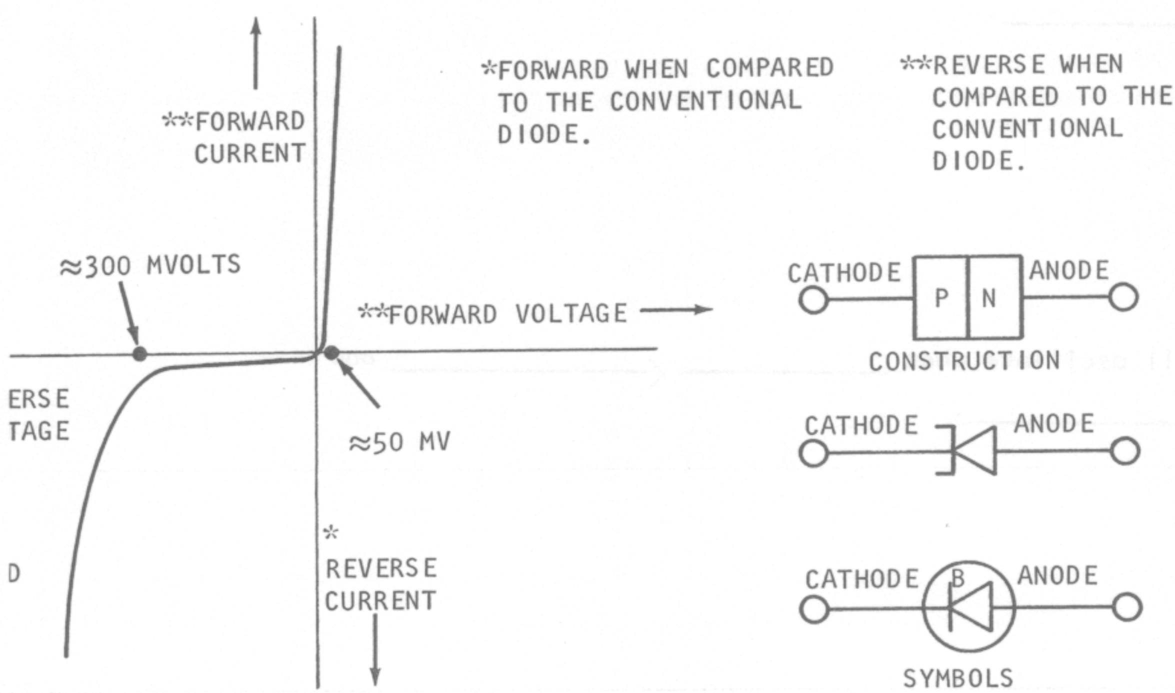


FIGURE 36A

36.12 Figure 36A compares the backward diode to the conventional diode. The backward diode has a __________ forward conducting drop and a
(low, high)

__________ peak inverse voltage rating when compared to the conventional
(low, high)
diode.

backward

36.13 An example of a circuit application of the backward diode is as a coupling diode in a tunnel diode switching circuit. The conducting drop of a conventional diode in larger than the switching voltage of a tunnel diode, therefore, the conventional diode cannot be used.

low
low

36.14** The P side serves as the ________________ in a backward diode, and it is used where a low conducting ________________ drop is desirable, and a limited non-conducting mode ________________ voltage can be tolerated.

no answer needed

36.15 END OF SET

cathode
voltage
breakdown

37 Fast switching diodes are designed for _______________ capacitance and low _______________ charge for faster forward and reverse recovery. Forward recovery occurs during the time it takes the diode to switch from _______________ current to a given _______________ equilibrium value. Reverse _________________ is the time interval between the time of application of a reverse switching voltage to a conducting diode, and the time at which reverse _________________ reaches a predetermined recovery level.

37.1 Diodes designed for fast switching service have their capacitance held to a minimum to enhance switching _____________.

low, small
stored
zero
forward
recovery
current

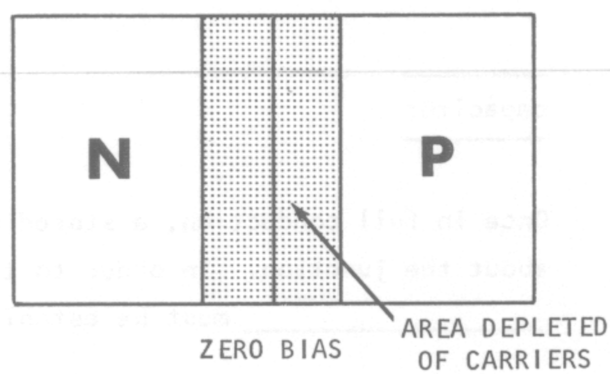
37.2 When a non-conducting diode has a forward switching voltage applied in an attempt to turn it on, it will take a period of time to reach full conduction.

speed, time, etc.

37.3 When a diode in full conduction is switched with a reverse switching voltage in an attempt to turn if off, a period of time is required to remove the ______________________ charge.

no answer needed

37.4 A diode with zero applied voltage is at equilibrium, and a ______________ region exists about the junction.



stored

37.5 The depletion region can be likened to the dielectric in a charged capacitor. The N and P regions on either side of the depletion region serves as the ____________________ of the capacitor.

depletion

37.6 Majority carriers must be moved into the depletion region and across the junction before the diode can conduct. This can be compared to charging a ________________________.

plates

37.7 A period of time is required to move majority carriers into the depletion region and across the junction where they become minority carriers and recombine. Moving carriers into the two sides can be related to ______________________ a capacitor.

capacitor

37.8 Once in full conduction, a stored charge of minority carriers exists about the junction. In order to turn the diode on, this _________________ ____________________ must be established.

charging

37.9 When an attempt is made to turn on a non-conducting diode very rapidly, the period of time between the 10% and 90% points on the forward current rise is termed forward recovery time.

stored charge

38.3 A reverse switching voltage should reverse bias the diode to turn it off. A ________________ voltage applied to the anode, or a ________________ voltage applied to the cathode will reverse bias a diode.

forward

38.4 A reverse switching voltage of sufficient magnitude will turn __________ a conducting diode.

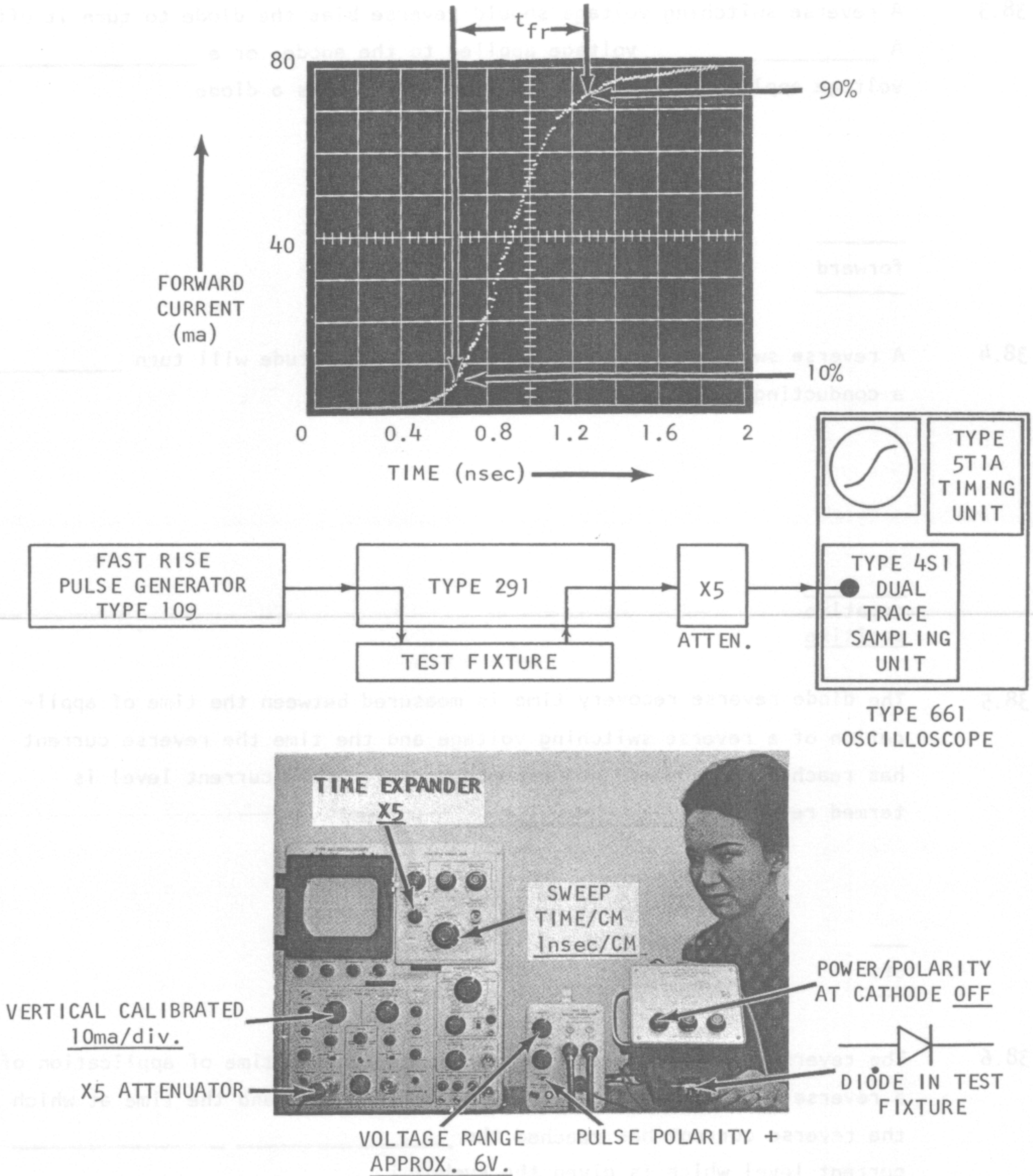
negative
positive

38.5 The diode reverse recovery time is measured between the time of application of a reverse switching voltage and the time the reverse current has reached a predetermined recovery level. This current level is termed reverse ____________________ current.

off

38.6 The reverse recovery time is measured between the time of application of a reverse switching voltage to a conducting diode and the time at which the reverse current has reached the ______________ ________________ current level which is given the symbol i_{rr}.

recovery



TEST SET-UP: TEKTRONIX TYPE 661 OSCILLOSCOPE WITH TYPE 5T1A TIMING UNIT AND TYPE 4S1 DUAL TRACE SAMPLING VERTICAL, TYPE 109 PULSE GENERATOR, AND TYPE 291 DIODE SWITCHING TIME TESTER. TOP PHOTO TAKEN WITH TYPE C-12 OSCILLOSCOPE CAMERA.

FIGURE 38A

a re-
near

t_{fr} of the diode in figure 38A is approximately __________ __________-seconds.

forward

cting
ise is

Figure 38B is a test set-up and measurement of diode reverse recovery time. The Type 291 has the diode initially conducting ________ma of ________ current.

0.6 nano

covery
conds.

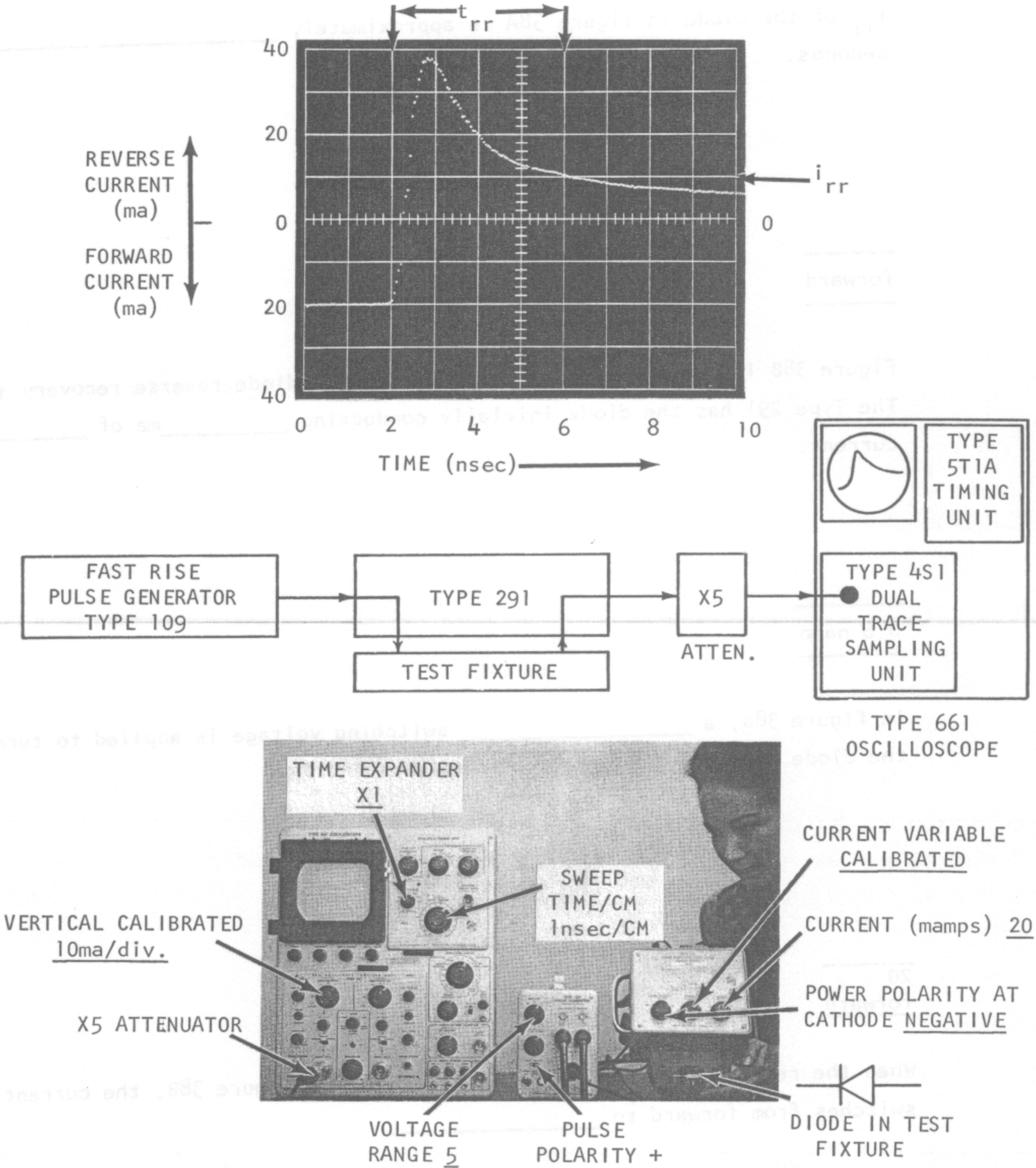
In figure 38B, a ______________ switching voltage is applied to turn the diode ______________.

20
forward

38A to

When the reverse switching voltage is applied in figure 38B, the current switches from forward to ____________.

reverse
off



TEST SET-UP: TEKTRONIX TYPE 661 OSCILLOSCOPE WITH TYPE 5T1A TIMING UNIT AND TYPE 4S1 DUAL TRACE SAMPLING VERTICAL, TYPE 109 PULSE GENERATOR, AND TYPE 291 DIODE SWITCHING TIME TESTER. TOP PHOTO TAKEN WITH TYPE C-12 OSCILLOSCOPE CAMERA.

FIGURE 38B

38.15 The reverse current in figure 38B is due to the __________ ____________ near the junction of the conducting diode.

reverse

38.16 The stored charge must be removed to turn off the diode. When sufficient stored charge has been removed for the current to reach reverse recovery current level ________, the diode is considered to be recovered.
(symbol)

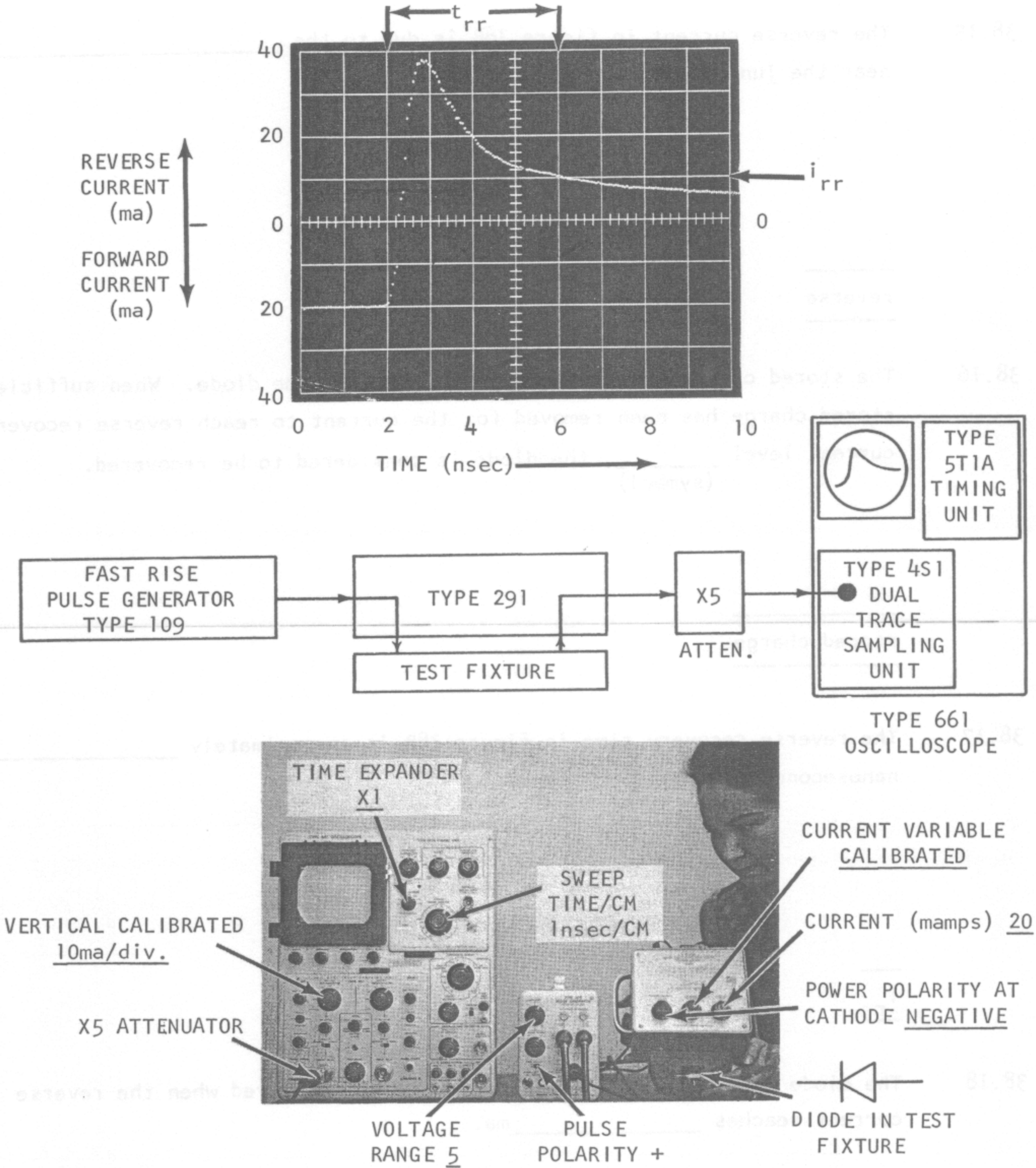
stored charge

38.17 The reverse recovery time in figure 38B is approximately ______________ nanoseconds.

i_{rr}

38.18 The diode in figure 38B is considered to be recovered when the reverse current reaches ______________ ma.

4



TEST SET-UP: TEKTRONIX TYPE 661 OSCILLOSCOPE WITH TYPE 5T1A TIMING UNIT AND TYPE 4S1 DUAL TRACE SAMPLING VERTICAL, TYPE 109 PULSE GENERATOR, AND TYPE 291 DIODE SWITCHING TIME TESTER. TOP PHOTO TAKEN WITH TYPE C-12 OSCILLOSCOPE CAMERA.

FIGURE 38B

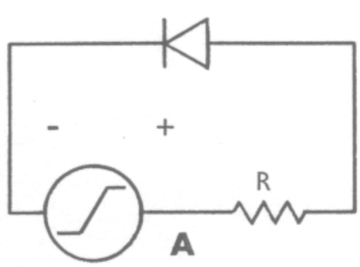
38.19 The current above the zero current line in figure 38B is a result of the diode's _______________ _______________.

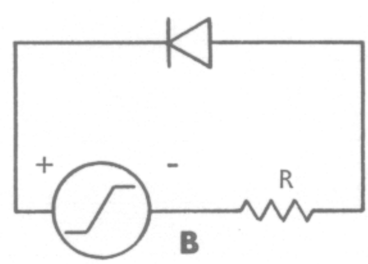
10

38.20 Increasing the forward current that the diode is conducting will ___________________ the stored charge and the reverse recovery time.

stored charge

38.21**





A is a __________________ switching voltage and B is a ___________ switching voltage. Forward recovery time is measured between the 10% and 90% points on the forward ________________ waveform of a diode driven by a forward switching voltage. Reverse recovery time is measured between the time of application of a reverse switching voltage to a conducting diode and the time that the reverse current reaches the _________________ __________________ current level (i_{rr}).

increase

38.22 END OF SET

forward
reverse
current
reverse recovery

39 Stored charge is given in ______________ of pico-________________ and is the amount of charge stored by a forward conducting diode. τ_q is given as a ratio of stored charge and forward ______________. It is generally stated in pico-coulombs per _________________ of forward _______________. Power handling of fast switching diodes is limited by ___________________ factors as/than other diodes.
(the same, different)

39.1 Stored charge is given in coulombs or pico-coulombs and its magnitude is dependent on the lifetime of the minority carriers and the amount of forward current in the diode.

coulombs
coulombs
current
milliampere
current
the same

39.2 Since minority carrier lifetime is constant for a given diode, the variable effecting stored charge is the magnitude of forward current.

no answer needed

39.3 The minority carrier lifetime which governs the magnitude of stored charge per unit of forward current is given the symbol "τ_q" and is constant for a given diode.

no answer needed

39.4 τ_q is generally stated as a ratio of stored charge to forward current, rather than stating time as its dimension.

no answer needed

39.5 Stored charge (Q_s) is dependent on the magnitude of forward current. The amount of stored charge will vary directly with the amount of forward ________________ for a given diode.

no answer needed

39.6 τ_q serves as a convenient factor that may be used to determine the amount of stored charge for a given amount of forward current.

$$Q_s = (\text{forward current}) \times (\underline{\hspace{3cm}})$$

current

39.7 τ_q is generally given in pico-coulombs per milliampere. Total stored charge can be found by taking the product of ______________ and the forward current in milliamperes.

τ_q

39.8 Given: τ_q = 10 pico-coulombs per milliampere, forward current = 0.06 amperes, stored charge = ______________ pico-coulombs.

τ_q

39.9 Fast switching diodes have design considerations for switching speed, but power limitations are set by the same factors as other diodes.

600

39.10 Maximum voltage, current and power are set by the ambient temperature, maximum operating temperature of the diode, and total ________________ resistance.

no answer needed

39.11 Switching diodes will have most of the same parameters and specifications as the rectifier diode with the addition of diode ________________ times and characteristics.

thermal

39.12** ____________ ____________ (Q_s) is given in coulombs or pico-coulombs. ____________ is generally given in pico-coulombs per milli-ampere. Switching diode maximum power is set by ____________ (the same, different) factors as/than other diodes.

switching

39.13 END OF SET

stored charge
τ_q
the same

40 The snap-off diode is designed for ________ (large, small) τ_q or stored charge per milliampere of forward current. Its distinguishing feature is a fractional nano-second ________ current fall time when switched with a reverse switching voltage. This portion of its characteristic is used for ________ risetime pulse generation. Adjusting the ________ current changes the storage time.

40.1 The term snap-off refers to the speed at which the diode reverse current cuts off when switched with a reverse switching voltage.

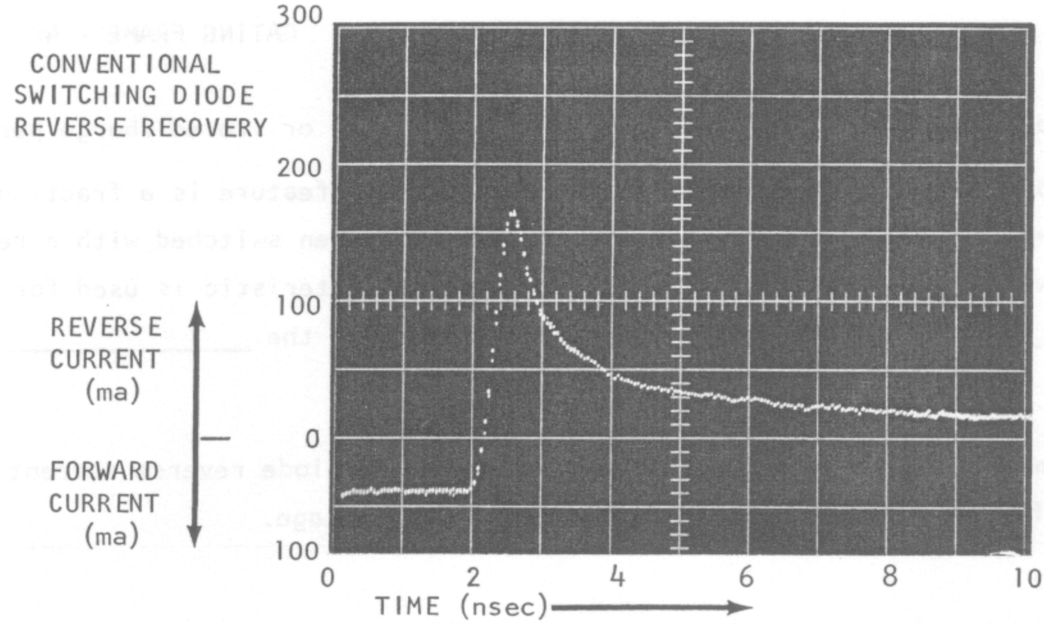
large
reverse
fast
forward

40.2 The snap-off diode is designed for a large τ_q, but care is taken that reverse current due to stored charge will decrease abruptly or ________ off.

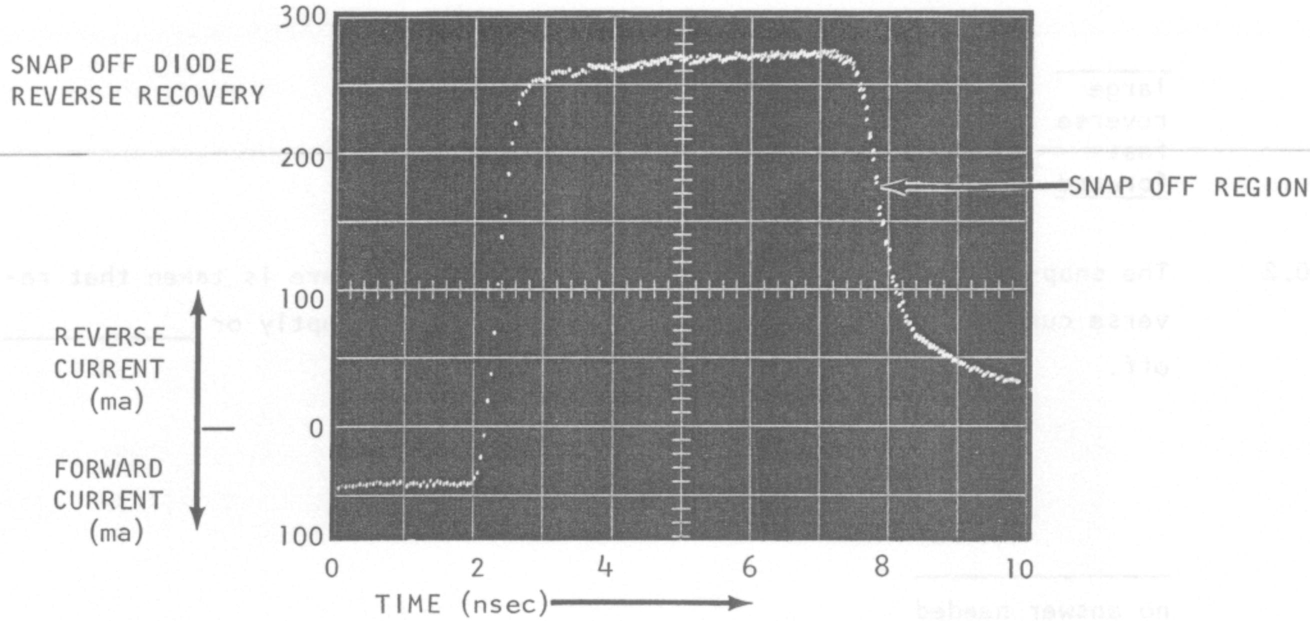
no answer needed

40.3 The conventional switching diode is designed for low minority carrier lifetime for low ________ charge.

snap



TEST SET-UP:
TEKTRONIX TYPE 661 SAMPLING OSCILLOSCOPE WITH TYPE 4S1 DUAL TRACE SAMPLING VERTICAL UNIT AND 5T1A TIMING UNIT, TYPE 109 PULSE GENERATOR, AND TYPE 291 DIODE SWITCHING TIME TESTER POWER SUPPLY WITH DIODE TEST FIXTURE. TOP TWO PHOTOS TAKEN WITH TEKTRONIX TYPE C-12 OSCILLOSCOPE CAMERA.



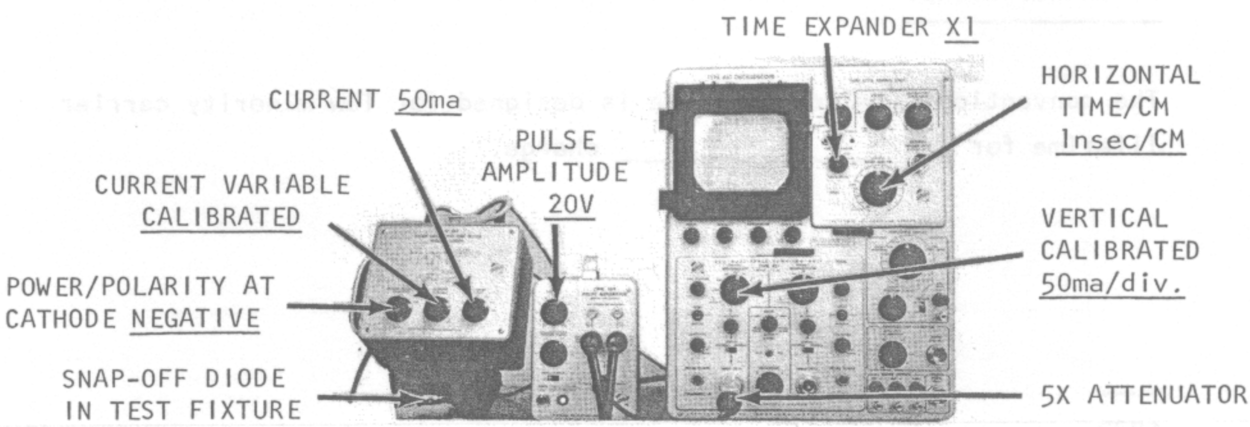


FIGURE 40A

40.4 Figure 40A indicates that the snap-off diode has very much ______ (more, less) stored charge per unit of forward current than the conventional switching diode.

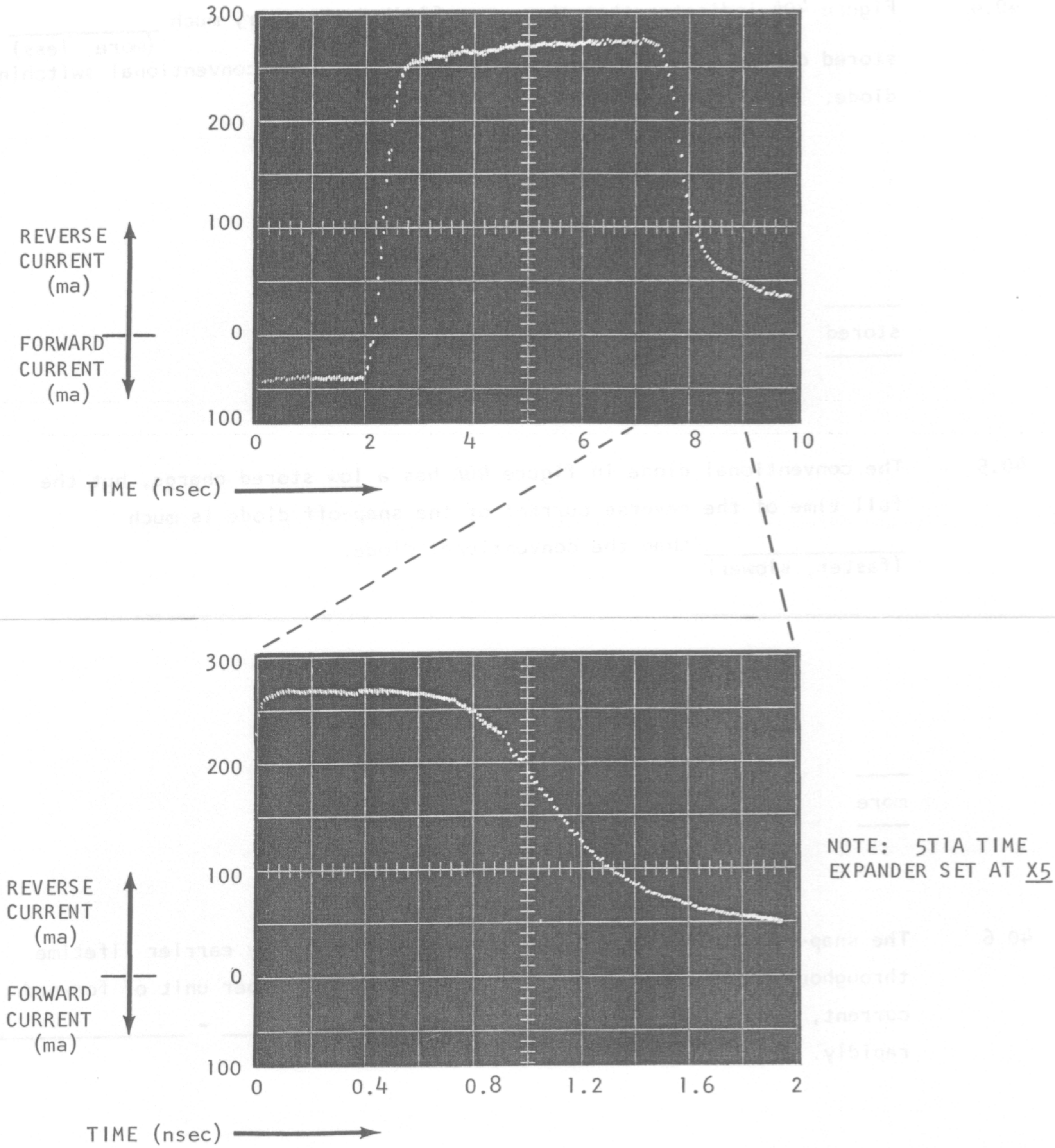
stored

40.5 The conventional diode in figure 40A has a low stored charge, but the fall time of the reverse current of the snap-off diode is much ______ (faster, slower) than the conventional diode.

more

40.6 The snap-off diode has controlled doping and minority carrier lifetime throughout the device to give a large stored charge per unit of forward current, but to have the reverse current ______ - ______ rapidly.

faster



TEST SET-UP: SAME AS FIGURE 40A EXCEPT LOWER PHOTO HAS TIME EXPANDER SET AT X5.

FIGURE 40B

40.7 The snap-off characteristic of the snap-off diode occurs in fractional ____________-seconds, as shown in figure 40B.

snap-off

40.8 Using the snap-off portion of the diodes characteristic as the leading edge of a generated pulse gives a fractional nano-second ____________ time pulse.

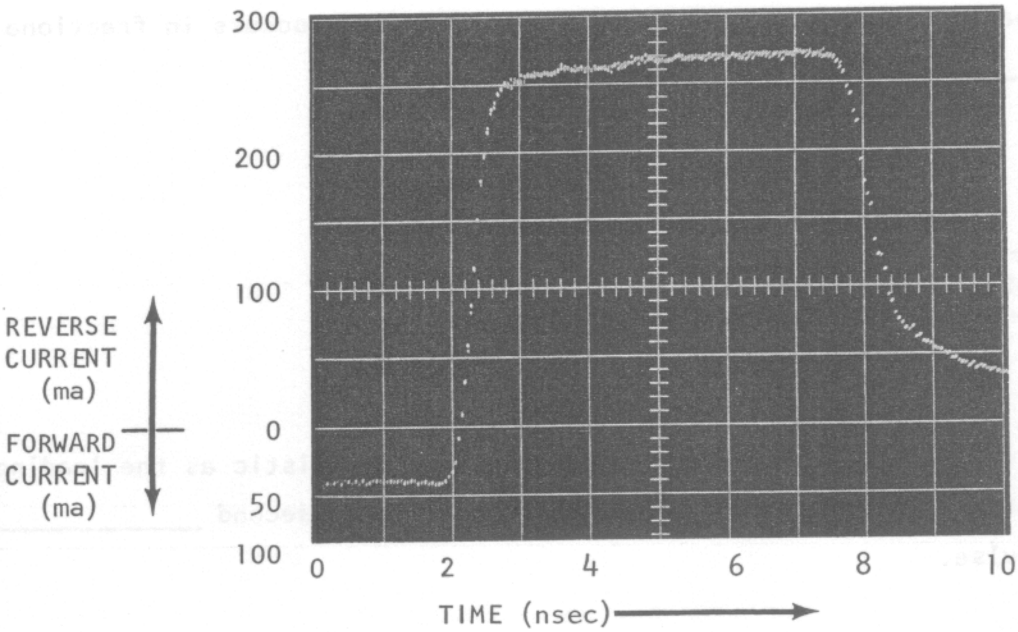
nano

40.9 The snap-off diode is used in circuitry to shape up the leading edge of generated current or voltage pulses. This is possible due to the rapid snap-off of its ______________ current.

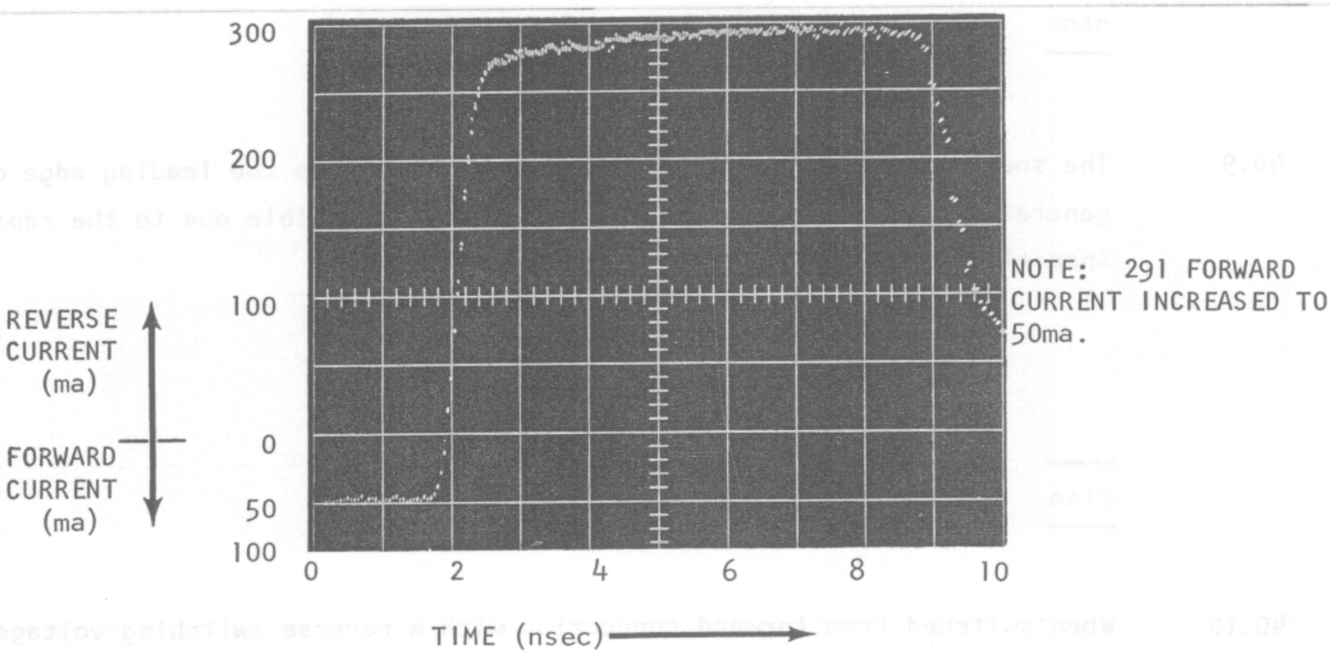
rise

40.10 When switched from forward conduction with a reverse switching voltage, the snap-off diode will continue to conduct for the duration of the stored charge and then __________-___________ in a fractional _______-second.

reverse or storage



SNAP-OFF DIODE REVERSE RECOVERY
WITH 40ma OF FORWARD CURRENT



SNAP-OFF DIODE REVERSE RECOVERY
WITH 50ma OF FORWARD CURRENT

TEST SET-UP: SAME AS FIGURE 40A WITH THE EXCEPTION OF THE TYPE 291 CURRENT INCREASED TO 50ma FOR THE LOWER PHOTO

FIGURE 40C

40.11 In the top photo in figure 40C, the total storage time is about ________ nano-seconds.

snap-off
nano

40.12 The lower photo in figure 40C has the forward current increased to 50 ma, and the storage time has increased to over ______________ nano-seconds.

6

40.13 Increasing the forward current increases the stored charge and the ______________ time of the snap-off diode.

7

40.14 The amount of delay between the application of the reverse switching voltage and the time snap-off occurs can be varied by varying ___________ ________________.

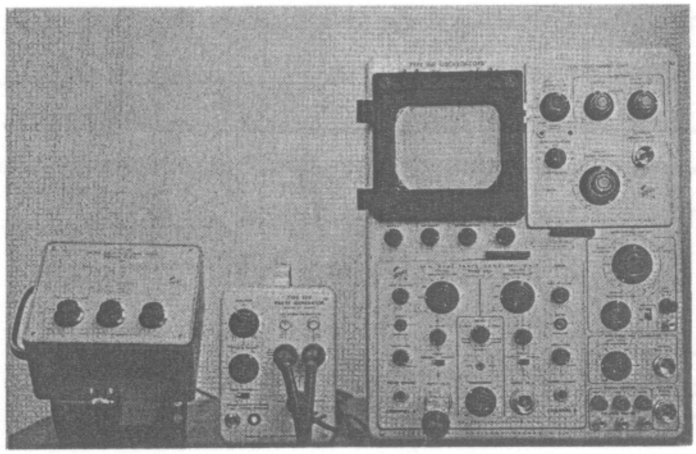
storage

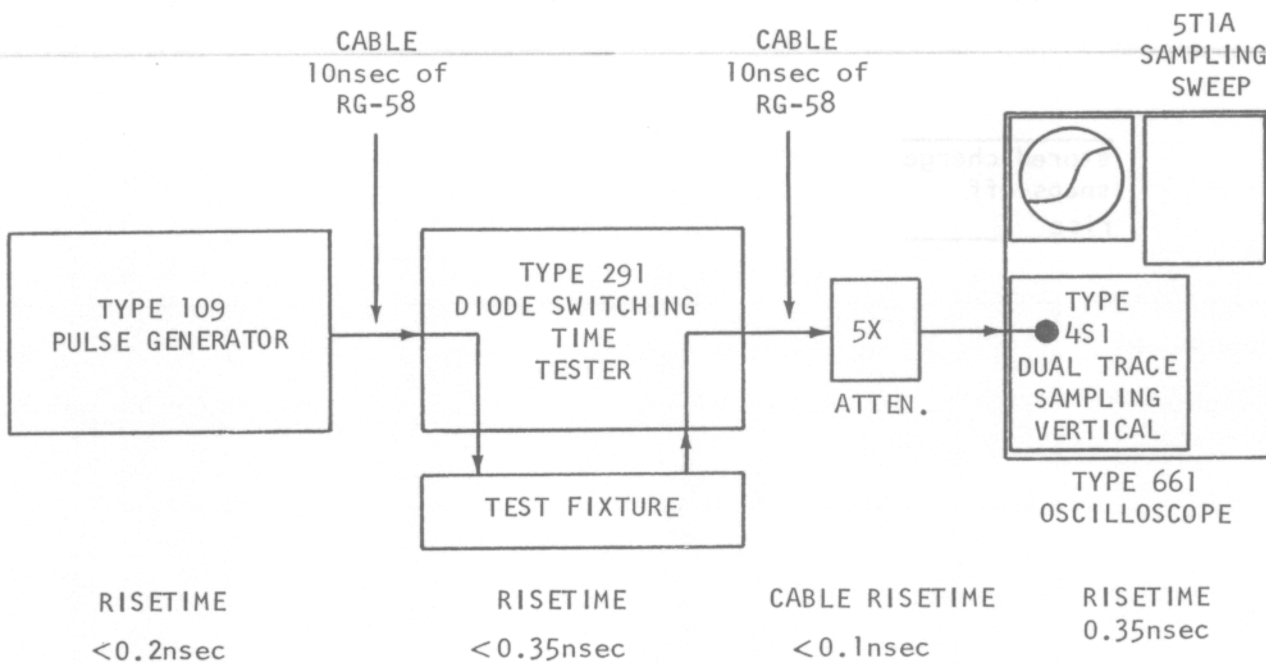
40.15** The snap-off diode has a large stored charge per unit of forward current and, when switched with a reverse switching voltage, continues to conduct for the duration of the ________________ ________________ and then ________________ ________________ abruptly. Varying the forward current varies the stored charge and the storage time. Using the snap-off region in pulse generation gives fast ______________ time pulses.

forward current

40.16 END OF SET

stored charge
snaps-off
rise





NOTE: Coaxial cable risetime is generally given as 0 to 50% risetime. To convert this to 10% to 90% risetime, use the factor 30 (i.e. 30 x 0-50% risetime ≈10 - 90% risetime).

FIGURE 41A

41 A diode's risetime is measured on the system in figure 41A, anu the measurement taken on the cathode ray tube is 0.65 nanoseconds. This is not the true diode risetime. The diode's risetime may be calculated from the formula ____
or the risetime of the ____________ without the ______________ may be measured and used in conjunction with the 0.65 nanosecond measurement to solve for true diode risetime.

41.1 A risetime measurement of 0.65 nanoseconds on the system in figure 41A is approximately equal to the square root of the sum of the squares of all the risetimes of the diode and the measurement system.

$$RT\ diode \approx \sqrt{RT_{measured}^2 - RT_{109}^2 - RT_{291}^2 - RT_{4S1/661}^2 - RT_{cables}^2}$$

system

diode

41.2

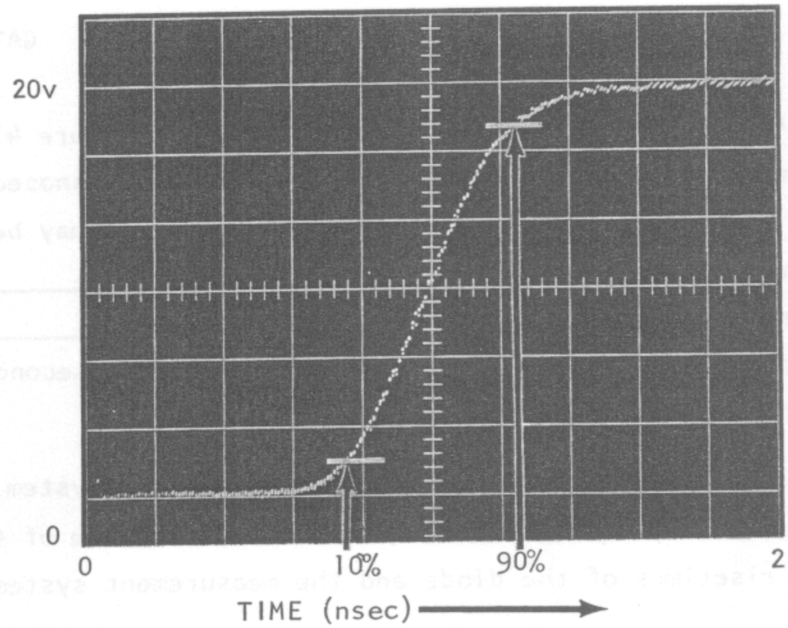
$$RT\ measured \approx \sqrt{RT_{diode}^2 + RT_{109}^2 + RT_{291}^2 + RT_{4S1/661}^2 + RT_{cables}^2}$$

no answer needed

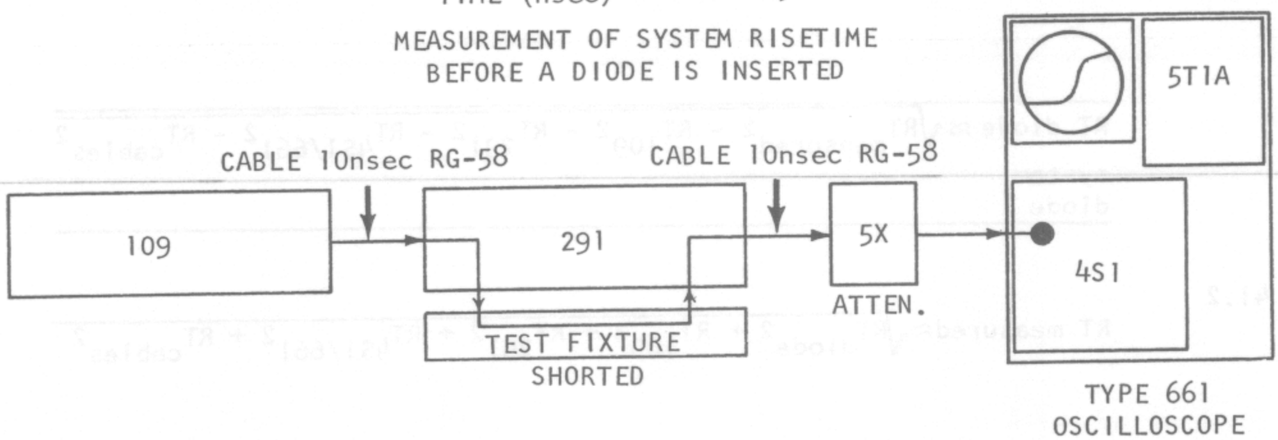
41.3 Squaring both sides and transposing:

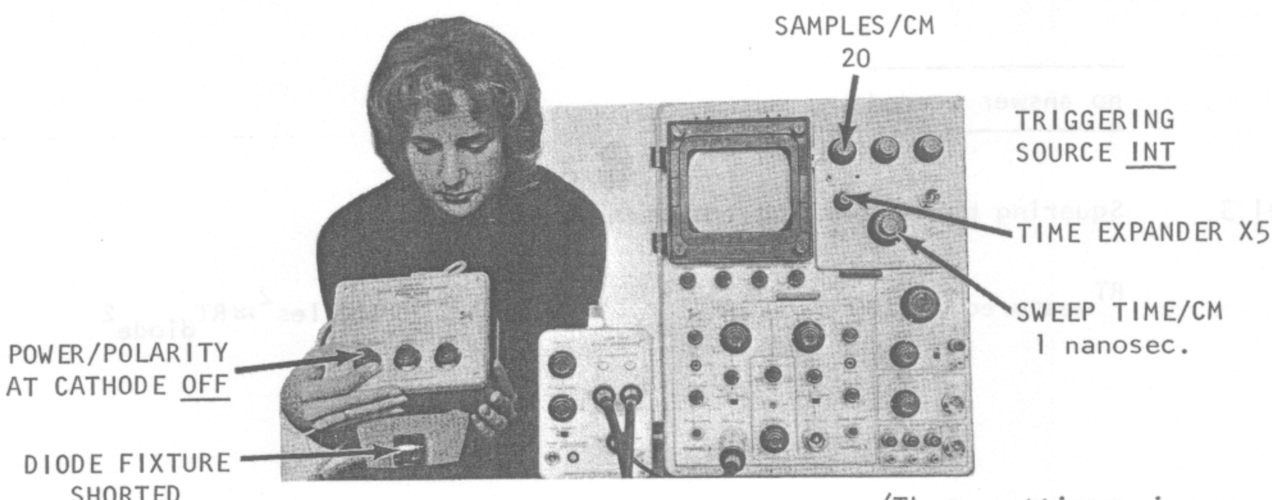
$$RT_{measured}^2 - RT_{109}^2 - RT_{291}^2 - RT_{4S1/661}^2 - RT_{cables}^2 \approx RT_{diode}^2$$

no answer needed



MEASUREMENT OF SYSTEM RISETIME
BEFORE A DIODE IS INSERTED





(These settings give a time/CM of 0.2 nanosec/CM.)

FIGURE 41B

41.4 Taking the square root of both sides:

$$RT_{diode} \approx \sqrt{RT_{measured}^2 - RT_{109}^2 - RT_{291}^2 - RT_{4S1/661}^2 - RT_{cables}^2}$$

no answer needed

41.5 To simplify the calculations, the risetime of the system without the diode can be measured and used in solving for ______________ risetime.

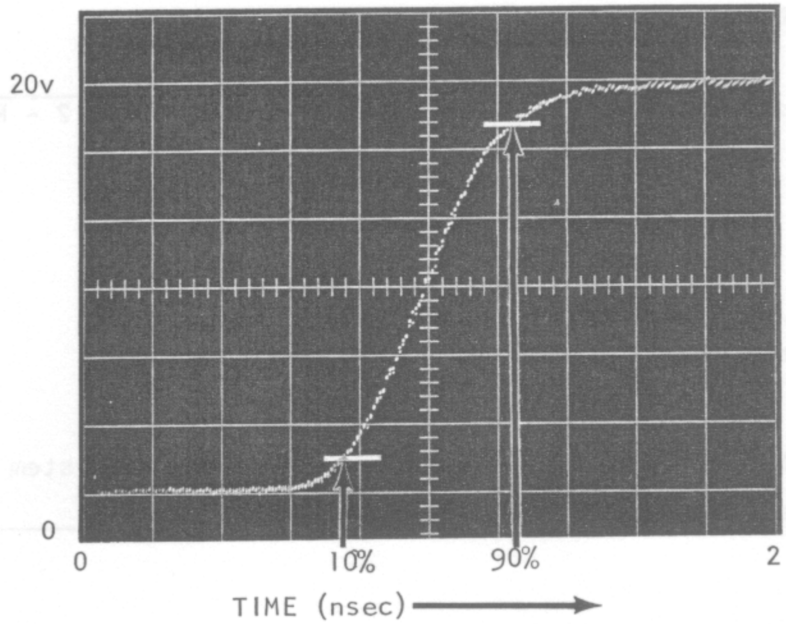
no answer needed

41.6 Figure 41B is the measurement of system risetime. The risetime of the system is about ________________ nanoseconds.

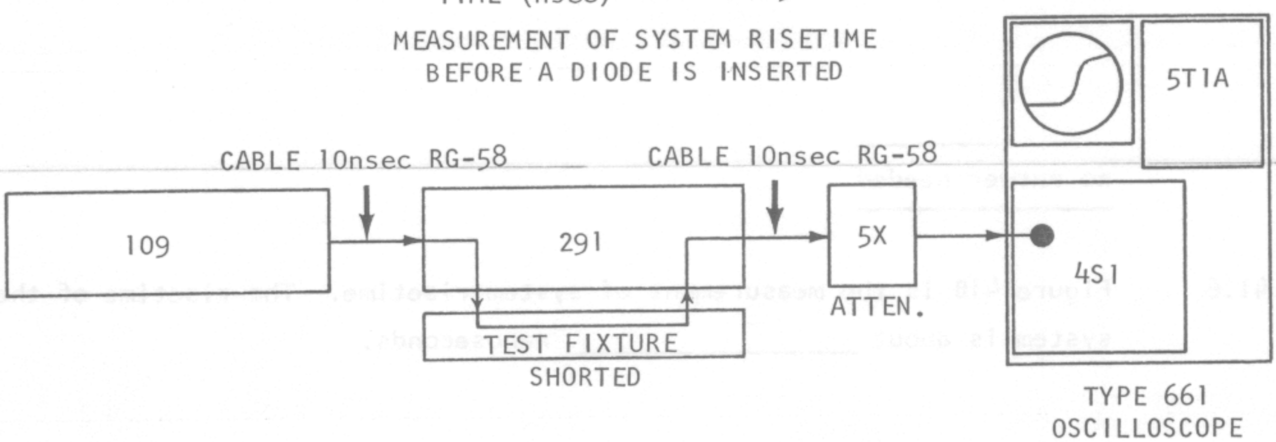
diode

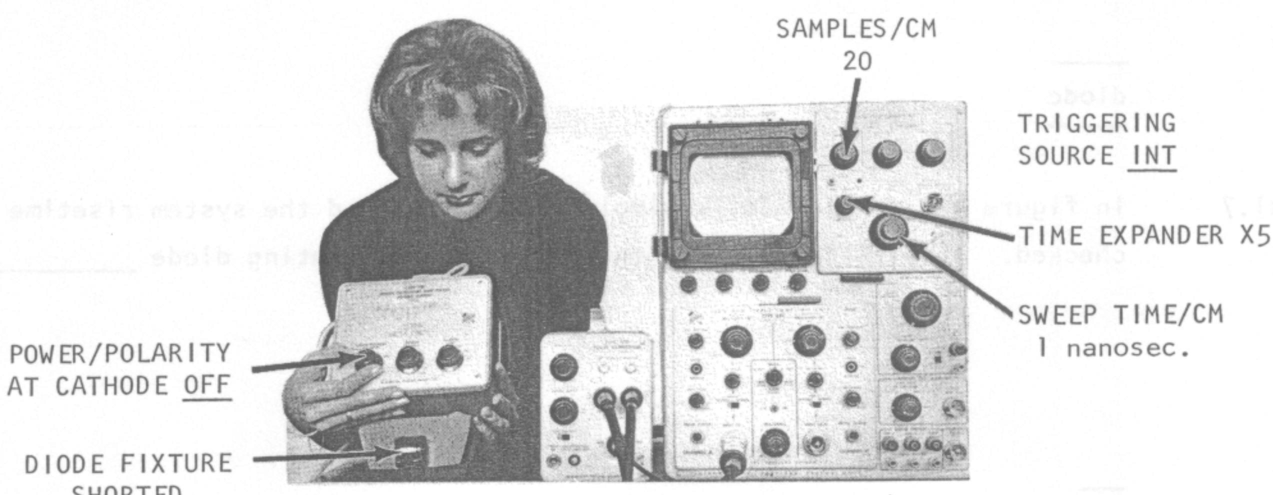
41.7 In figure 41B, the diode is simply shorted out and the system risetime checked. This risetime can then be used in calculating diode __________.

0.5



MEASUREMENT OF SYSTEM RISETIME
BEFORE A DIODE IS INSERTED





(These settings give a time/CM of 0.2 nanosec/CM.)

FIGURE 41B

41.8 Diode risetime is equal to:

$$RT_{diode} \approx \sqrt{RT_{measured}^2 - RT_{system}^2}$$

risetime

41.9 The risetime of the system in figure 41B is 0.5 nanoseconds. A measured risetime of 0.65 nanoseconds would indicate that the diode's risetime is approximately ____________ nanoseconds.

$$RT_{diode} \approx \sqrt{RT_{measured}^2 - RT_{system}^2}$$

$$\approx \sqrt{(0.65 \times 10^{-9})^2 - (0.5 \times 10^{-9})^2}$$

no answer needed

41.10** A diode's risetime is measured as 0.8 nano-seconds on the system in figure 41A. The true diode risetime is approximately ____________________________ nanoseconds.

0.4146

41.11 END OF SET

$$RT_{diode} \approx \sqrt{RT_{measured}^2 - RT_{system}^2}$$

$$\approx \sqrt{0.8 \text{ nanosec}^2 - 0.5 \text{ nanosec}^2}$$

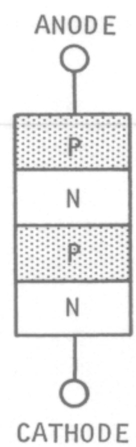
$$\approx \sqrt{(0.64 - 0.25)} \text{ nanosec}$$

$$\approx \sqrt{.39} \text{ nanosec}$$

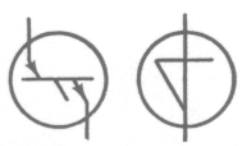
$$\approx 0.625 \text{ nanoseconds}$$

42 ________________ is the symbol for a four layer or shockley diode. It will remain non-conducting until the applied voltage exceeds the ________ switching voltage. With ______________ voltage applied, it will show the characteristics of a silicon rectifier. The diode will switch from "on" to "off" when the current is reduced to below minimum ______________ ______________.

42.1 The four layer or shockley diode is a four layer, triple junction device.

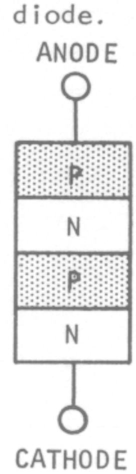


____



forward
reverse
holding current

42.2 The N type end serves as the ______________, and the P type end serves as the ____________ of the four layer diode.



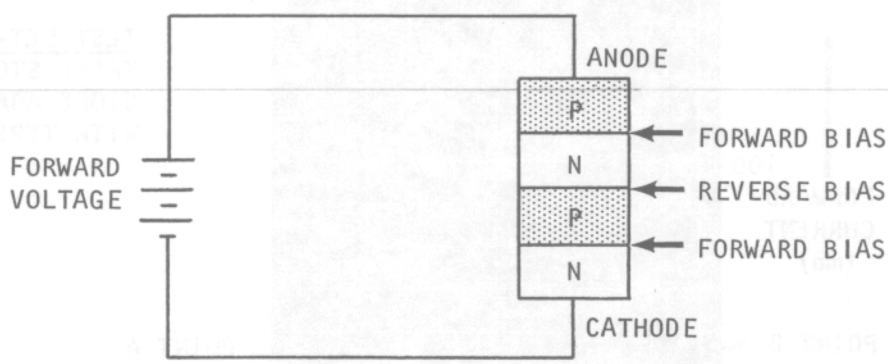
____

no answer needed

42.3 Applying a positive voltage to the anode or a negative voltage to the cathode is forward voltage to the four layer diode.

cathode
anode

42.4 Forward voltage will attempt to forward bias two of the junctions, but ____________ bias the third junction.



no answer needed

42.5 The point at which the center junction starts to avalanche is termed the forward switching voltage and the diode switches <u>on</u> at this point.

reverse

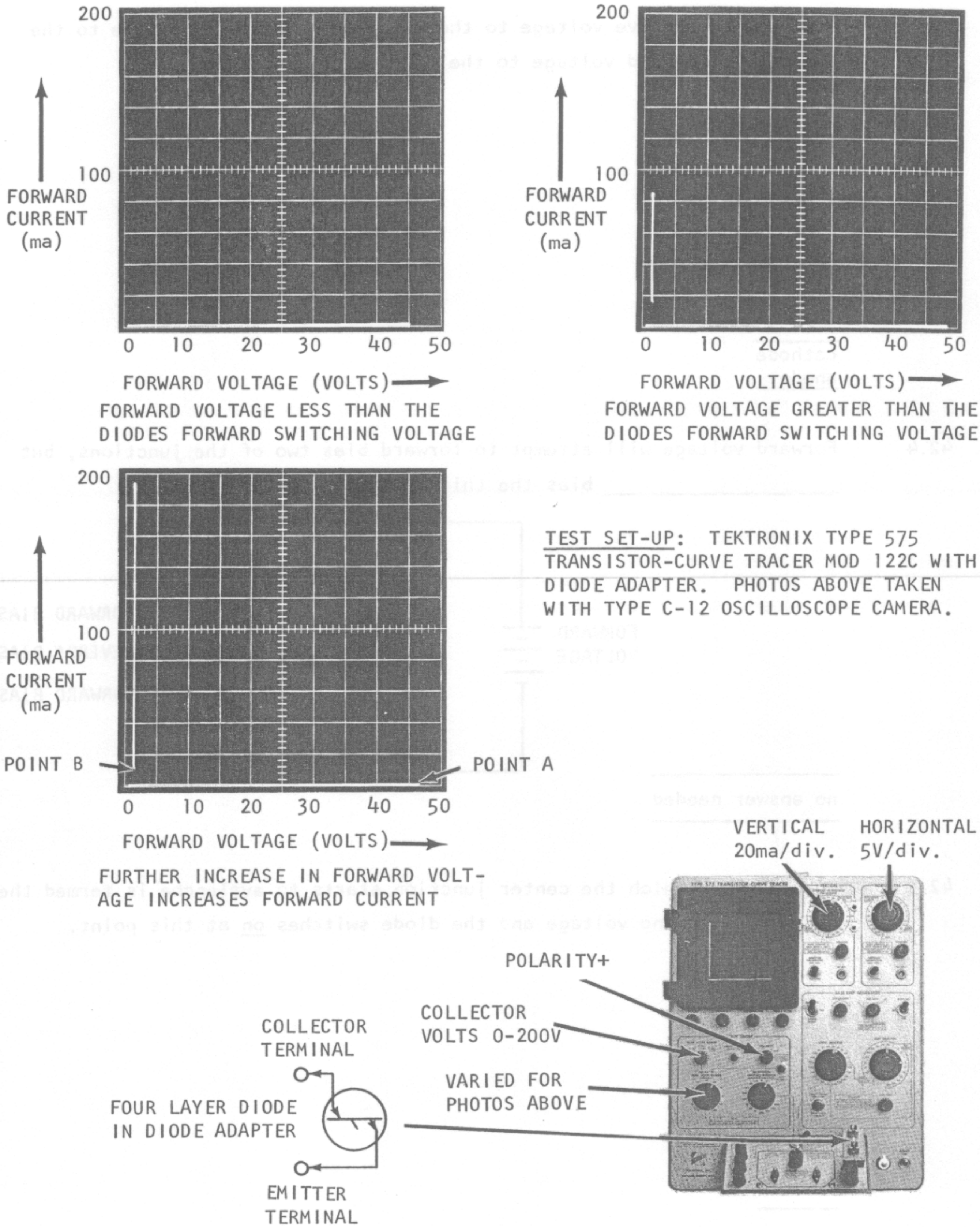

200
100
FORWARD
CURRENT
(ma)
0 10 20 30 40 50
FORWARD VOLTAGE (VOLTS)
FORWARD VOLTAGE LESS THAN THE
DIODES FORWARD SWITCHING VOLTAGE
200
100
FORWARD
CURRENT
(ma)
0 10 20 30 40 50
FORWARD VOLTAGE (VOLTS)
FORWARD VOLTAGE GREATER THAN THE
DIODES FORWARD SWITCHING VOLTAGE
200
100
FORWARD
CURRENT
(ma)
POINT B
POINT A
0 10 20 30 40 50
FORWARD VOLTAGE (VOLTS)
FURTHER INCREASE IN FORWARD VOLT-
AGE INCREASES FORWARD CURRENT
TEST SET-UP: TEKTRONIX TYPE 575
TRANSISTOR-CURVE TRACER MOD 122C WITH
DIODE ADAPTER. PHOTOS ABOVE TAKEN
WITH TYPE C-12 OSCILLOSCOPE CAMERA.
VERTICAL
20ma/div.
HORIZONTAL
5V/div.
POLARITY+
COLLECTOR
VOLTS 0-200V
VARIED FOR
PHOTOS ABOVE
COLLECTOR
TERMINAL
FOUR LAYER DIODE
IN DIODE ADAPTER
EMITTER
TERMINAL

FIGURE 42

42.6 When the forward switching voltage is exceeded, the diode switches to its conducting state. Its resistance changes from megohms to a few ohms in a micro-second, typically.

no answer needed

42.7 The voltage across the diode ______________ (increases, decreases) rapidly when the forward switching voltage is exceeded.

no answer needed

42.8 Figure 42 shows the EI curve of a four layer diode. Point A indicates the ____________ ____________ ____________.

decreases

42.9 Point B is the minimum current that will maintain the diode in the ______________ condition and it is termed "holding current".

forward switching voltage

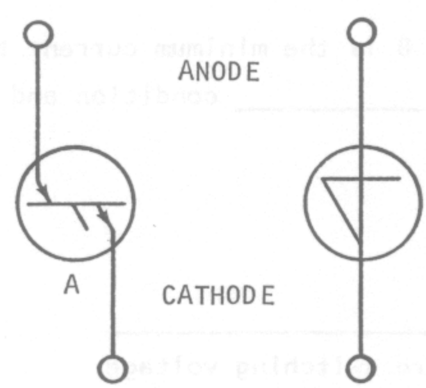
42.10 Reducing the current below the minimum holding current (I_h) level will cause the diode to switch back to the non-__________________ state.

on or conducting

42.11 To maintain the diode in the ON condition, the current must be held above the minimum __________ ______________ level.

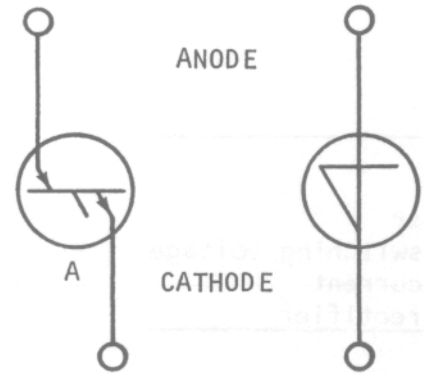
conducting

42.12 The symbols used for the four layer or shockley diode both indicate that four layers are present. Symbol A is used by Tektronix.



holding current

42.13 The point of the four in one symbol for the four layer diagram indicates the ______________ end of the device. In the symbol used by Tektronix, the tip of the arrow pointing away from the center indicates the ______________ end of the device.

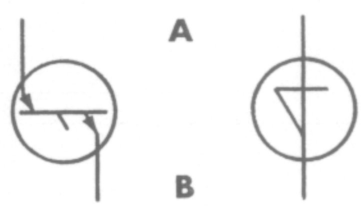


no answer needed

42.14 Application of reverse voltage to a four layer diagram reverse biases ________(#) of the three junctions, and the reverse EI curve resembles that of a silicon rectifier. Reverse current will increase greatly when avalanche breakdown occurs. (LIMITED BY THE SERIES RESISTANCE.)

cathode
cathode

42.15**



A is the ________________ and B is the ______________ of the symbols shown for the ______________ ______________ diode. The diode will turn on when the ____________ ______________ ______________ is exceeded and will switch off when current is reduced below the minimum ____________________ ____________________. The reverse voltage EI curve resembles the ______________ __________________ reverse voltage EI curve.

two

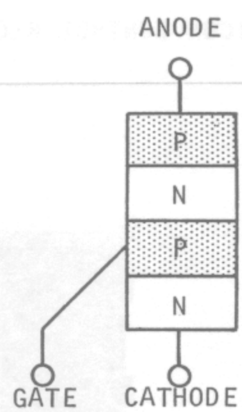
42.16 END OF SET

anode cathode four-layer forward switching voltage holding current silicon rectifier

43 is the symbol for a __________ __________ rectifier. A is the __________, B is the __________, and C is the __________. It is similar in construction to the four layer diode with the addition of the __________. Applying a __________ current reduces the forward switching or __________ voltage. The device may be switched on with a __________ current pulse, but the current must be reduced below minimum __________ current to return it to the "off" condition.

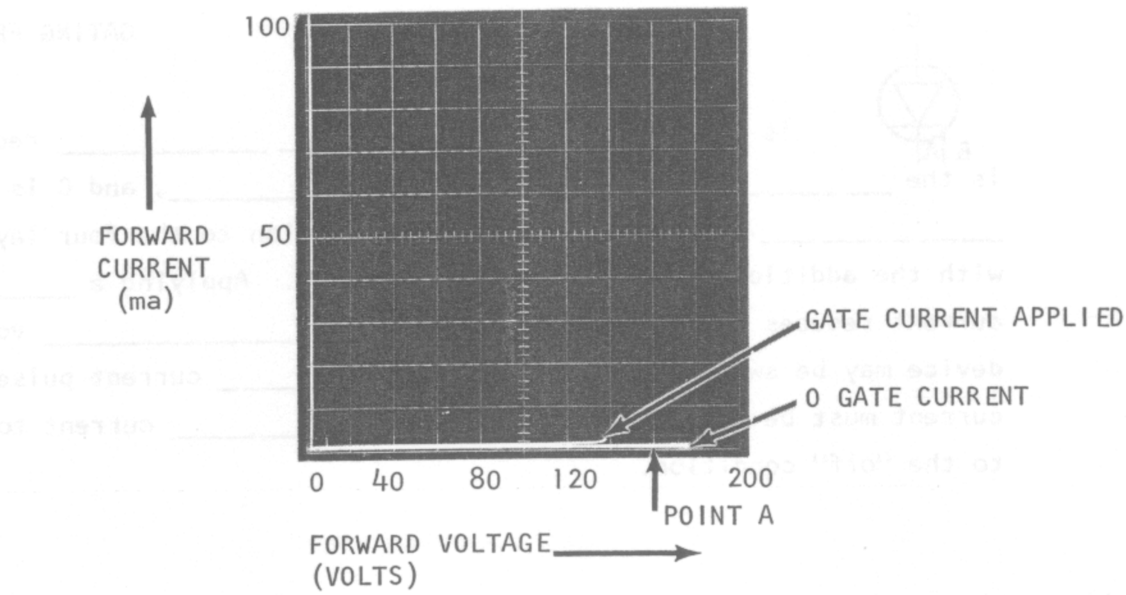
silicon control
cathode
gate
anode
gate
gate
blocking
gate
holding

43.1 The construction of the silicon control rectifier (SCR) is similar to the four layer diode with the addition of the __________ connection.

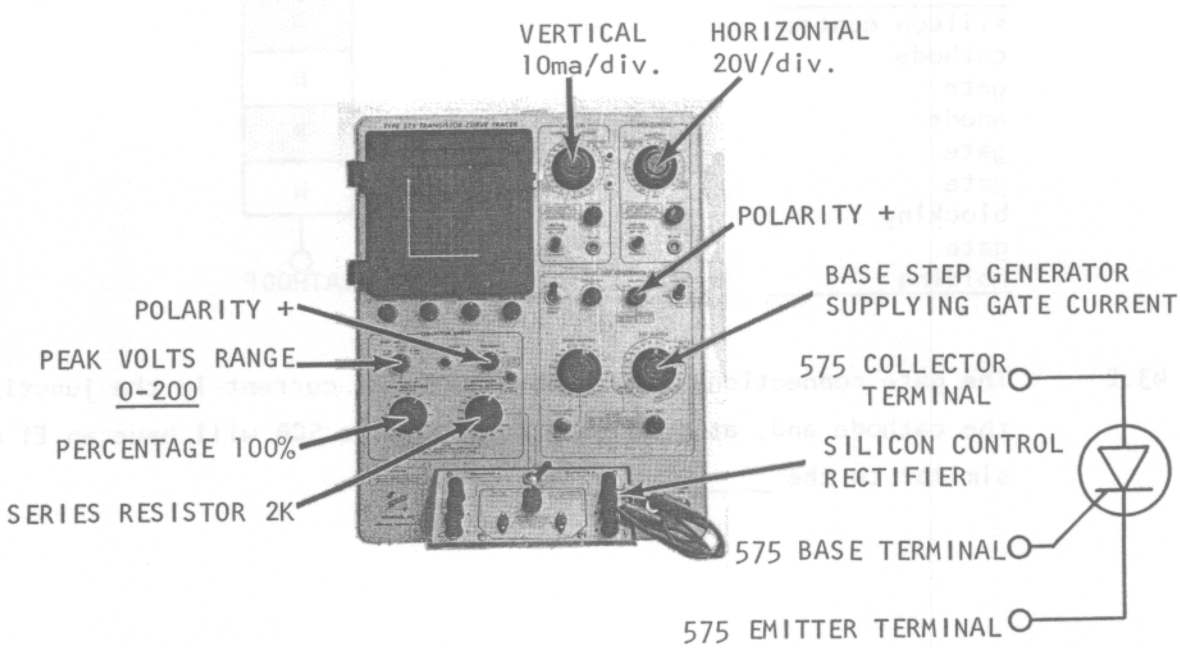


gate

43.2 The gate connection allows control of the current in the junction nearest the cathode and, at zero gate current, the SCR will have an EI curve similar to the __________ layer diode.



SILICON CONTROL RECTIFIER EI CHARACTERISTIC



TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR-CURVE TRACER MOD 122C
TOP PHOTO TAKEN WITH TYPE C-12 OSCILLOSCOPE CAMERA

FIGURE 43A

43.3 Application of a gate current to the SCR will raise the cathode current level and reduce the forward voltage required to switch to an "on" condition.

four

43.4 Figure 43A shows the EI characteristics of the SCR with zero gate current and with an applied gate current. The forward switching voltage varies ________________ (inversely, directly) as gate current varies.

no answer needed

43.5 With the applied voltage at point A in figure 43A, the diode will be ________ (on, off) quiescently with zero gate current applied.

inversely

43.6 Applying a gate current of the magnitude shown in figure 43A will reduce the diode's forward switching voltage below point A and the diode will switch on.

off

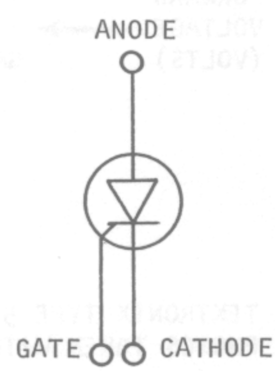
43.7 The diode current must be reduced below minimum ____________ current to turn the diode off.

no answer needed

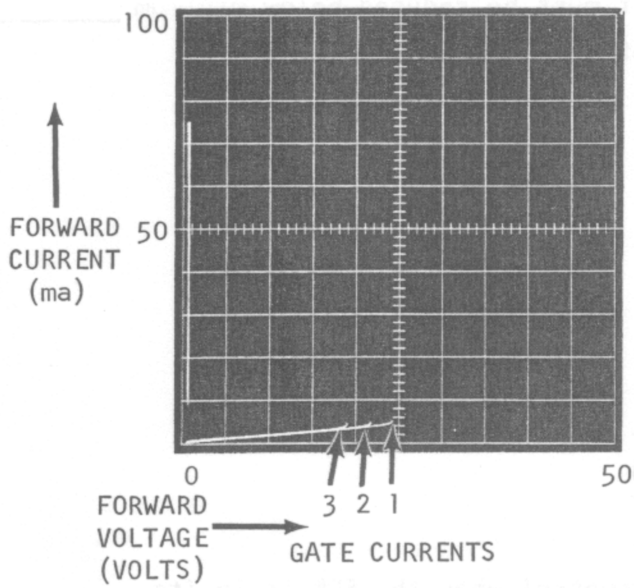
43.8 The gate has no control when the SCR is in its ______________ state.

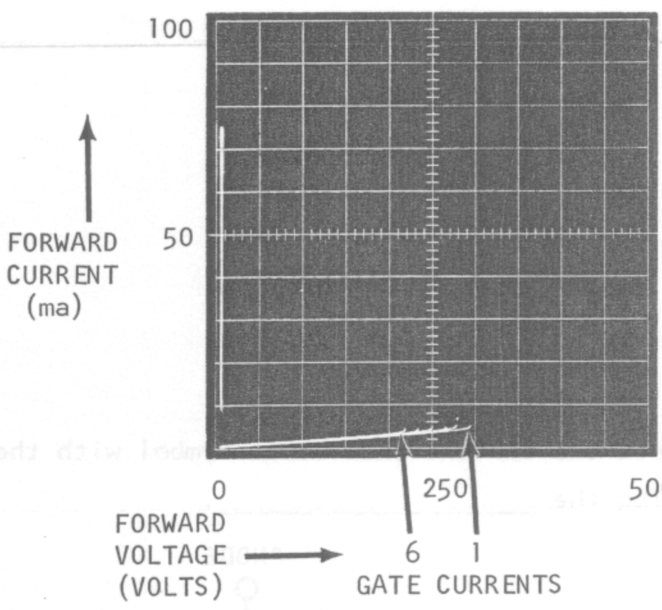
holding

43.9 The SCR symbol uses the conventional diode symbol with the addition of the line indicating the ________________.



on



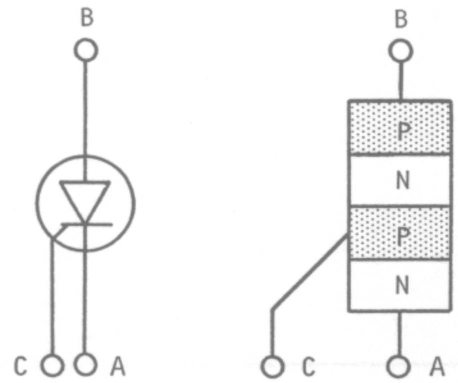


NOTE: GATE CURRENTS INCREASE WITH 1 THE LOWEST MAGNITUDE.

TEST SET-UP: TEKTRONIX TYPE 575 TRANSISTOR CURVE TRACER, MOD 122C.
PHOTOS TAKEN WITH TYPE C-12 OSCILLOSCOPE CAMERA.

FIGURE 43B

43.10 The symbol for an SCR is shown with a rough cross section. A is the ________________, and C is the ________________.



gate

43.11 Figure 43B shows the SCR at several values of gate currents. Forward switching or blocking voltage decreases as gate current is ____________.

cathode
gate

43.12 A small current pulse applied to the gate can switch large amounts of power with the SCR in suitable circuitry.

increased

43.13 A large switched power gain can be accomplished with an SCR with the _______________ as the input.

____
no answer needed

43.14** ___________________ is the symbol for a silicon control rectifier. Except for the gate, it is similar in construction to the _________ ____________ diode. The forward switching voltage varies _____________________ (inversely, directly) as gate current varies. Application of a gate current can be used to turn the diode on, but diode current must be reduced below minimum ________________ ______________ to turn it off.

gate

43.15 END OF SET

four layer
inversely
holding current

SELF TEST

Read each question carefully studying any diagrams provided and select the most correct answer.

1. Surrounding the material to be doped with the dopent in a gaseous form, and then subjecting it to heat is termed doping by ____________.

   a. thermodynamics
   b. diffusion
   c. epitaxial deposition
   d. planar masking

2. Close control of silicon rectifier characteristics is accomplished by doping with the ____________ process in high ____________ silicon.

   a. epitaxial layers, resistance
   b. rate growing, resistance
   c. diffusion, resistance
   d. rate growing, reactance

3. Maximum operating temperature of silicon rectifiers is about ____________ degrees centigrade.

   a. 175
   b. 100
   c. 325
   d. 75

4. When sufficient voltage is applied to turn on a diode in the forward direction, or cause breakdown in the reverse direction, the current is ____________ limited.

   a. resistance
   b. depletion layer
   c. stored charge
   d. majority carrier

5. A forward biased silicon diode exhibits a ____________ temperature coefficient of voltage at low currents, which means the diode voltage will ________ with an increase in temperature.

   a. positive, increase
   b. negative, increase
   c. positive, decrease
   d. negative, decrease

6. A silicon diode in avalanche breakdown has a _______________ temperature coefficient of voltage.

   a. negative
   b. positive
   c. 0%
   d. -1.2V/degree centigrade

7. The peak value of a-c voltage that can be applied to a silicon rectifier is limited by the diodes' _______________ rating.

   a. peak forward voltage drop
   b. maximum forward current
   c. maximum reverse current
   d. peak inverse voltage

8. The forward voltage drop of a silicon diode will vary with _______________ and _______________.

   a. forward current, series resistance
   b. junction capacity, ambient temperature
   c. forward current, ambient temperature
   d. ambient temperature, stored charge

9. The diode's forward current and voltage can be used to calculate diode's forward _______________ and _______________.

   a. power dissipation, resistance
   b. biasing, resistance
   c. capacitance, time constant
   d. reactance, resistance

10. Maximum steady state power dissipation of a silicon rectifier is limited by the _______________, _______________, and _______________.

    a. series resistance, thermal resistance, maximum junction capacity
    b. thermal resistance, maximum junction temperature, ambient temperature
    c. thermal resistance, thermal time constant, thermal capacity
    d. series resistance, applied voltage, ambient temperature

11. Attaching a silicon rectifier to an external heat sink reduces total _______________.

    a. power dissipation
    b. ambient temperature
    c. thermal capacity
    d. thermal resistance

12. Silicon rectifiers are stacked in series to increase the __________ rating.

a. peak inverse voltage
b. forward current
c. forward voltage
d. reverse current

13. For proper operation, series stacked rectifiers must have near equal __________ __________ and __________ __________, or they may be damaged.

a. reverse resistances, forward voltages
b. stored charges, reverse resistances
c. forward voltages, forward currents
d. peak inverse voltages, reverse currents

14. Shunting resistors may be added to series stacked silicon rectifiers to minimize the effects of unequal ______________.

a. stored charges
b. forward voltages
c. reverse resistances
d. forward currents

15. Shunting capacitors may be added to series stacked silicon rectifiers to minimize the effects of unequal ______________.

a. reverse resistances
b. forward currents
c. stored charges
d. forward voltages

16. A junction at equilibrium has the two ends separated by a depletion region, and serves as a ____________ that may be varied by application of _________.

a. resistor, light energy
b. inductor, voltage
c. capacitor, voltage
d. conductor, pressure

17.

is the symbol for a ________________.

a. voltage variable capacitor
b. snap-off diode
c. step recovery diode
d. temperature compensated zener diode

18. The name zener diode is misleading because ____________________.

a. it was developed by Mr. Esaki
b. many zeners operate in avalanche breakdown
c. it is not really a diode at all
d. most zeners operate in tunnel breakdown

19. The zener diode normally operates in the ______________ region of its EI characteristic.

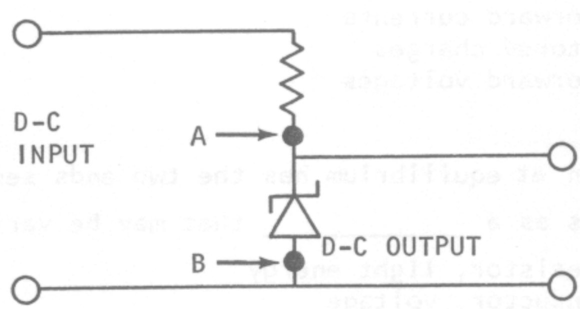
a. reverse breakdown
b. low reverse current
c. high forward current
d. forward saturation

20. The point of entry into the normal zener diode operating region of the EI curve is termed the _________________.

a. zener zone
b. push through point
c. diffusion point
d. zener knee

21. When operated as a voltage reference, the zener diode circuit shown will have electron movement from ____________ to ____________ through the diode.

a. B, A
b. A, B



22. Power dissipation by the zener diode is limited by ____________ considerations as/than other diodes.

a. different
b. the same

23. The number 10M47Z5 indicates a ____________ watt zener diode.

a. 47
b. 5
c. 10
d. 1/4

24. The number 50M47Z indicates that the zener diode has a ________% nominal zener voltage tolerance.

a. 50
b. 47
c. 5
d. 20
e. 10

25. The voltage regulator (VR) tube is limited to a minimum voltage of about ______________ volts, while the zener is available over the entire voltage range up to several hundred volts.

a. 12.3
b. 70
c. 105
d. 28

26. The noise level generated in a zener diode is ________________ as/than the noise level generated in a VR tube.

a. much less
b. about the same
c. much greater

27. A shunting ______________ will reduce the noise level in the zener diode.

a. capacitor
b. conventional diode
c. resistor
d. inductor

28. A zener diode operating in _____________ breakdown has a positive temperature coefficient of voltage.

a. zener
b. tunnel
c. avalanche
d. punch through

29. A forward biased diode at low currents has a ______________ temperature coefficient of voltage.

a. positive
b. negative
c. zero

36. Reverse voltage applied to a tunnel diode results in increased tunneling from the ______________ to the ____________ side.

    a. N, P
    b. P, N

37. The magnitude of tunnel diode peak current (I_p) is determined by junction ______________.

    a. geometry
    b. doping levels
    c. forward voltage
    d. reverse voltage

38. Valley current is measured at a point between __________ and ___________.

    a. tunnel breakdown, avalanche breakdown
    b. zero bias, peak current
    c. peak current, normal forward turn on
    d. normal forward turn on, avalanche breakdown

39. A negative resistance can be defined as a resistance that will ____________ power.

    a. generate
    b. dissipate
    c. store

40. The tunnel diode will serve as an amplifier when placed in proper circuitry and operated ______________________.

    a. on the first and second positive slopes
    b. on the first positive slope only
    c. in the negative resistance region and the first positive slope
    d. in the negative resistance region only.

41. Current amplification can be accomplished by operating the tunnel diode in an amplifier configuration in _______________ with its load resistor.

    a. series
    b. parallel

42.

A B C D

Symbol ____________ is not a symbol for a tunnel diode.

    a. A
    b. B
    c. C
    d. D

43. To serve as an amplifier, the negative resistance of the tunnel diode must be __________ to/as/than the total circuit positive resistance.

a. greater
b. less
c. as large
d. equal

44. The total resultant conductance of a tunnel diode amplifier circuit must be ____________.

a. inductive
b. capacitive
c. negative
d. positive

45. The tunnel diode will switch between positive slopes when the circuit positive resistance is ____________ the tunnel diode negative resistance.

a. less than
b. equal to
c. greater than

46. The positive resistance of the Type 575 Transistor Curve Tracer generally makes it impossible to observe the negative resistance region of the tunnel diode EI curve, since it forces the tunnel diode to operate in the _________ mode.

a. switching
b. amplifier
c. stable
d. carrier insertion

47. A tunnel diode switch can be current or voltage driven and will switch between ___________ slopes in fractional __________ seconds.

a. negative, pico
b. positive, milli
c. positive, atto
d. positive, nano

48. To switch a tunnel diode from its high state to its low state requires that the current be _____________.

a. increased above peak current
b. decreased below valley current
c. cut-off completely
d. increased to diode saturation

49. The majority of the supply voltage in a tunnel diode switching configuration will be across the diode when it is in its ____________ state.

a. high
b. low

50. A diode with doping levels and construction similar to a tunnel diode, but with near zero peak current, is termed a ____________ diode.

a. voltage variable capacitor
b. snap-off
c. half tunnel
d. backward

51. A diode that offers a very low conducting voltage drop when used as a conventional rectifying diode is the ____________ diode.

a. snap-off
b. snap-on
c. step recovery
d. half tunnel
e. backward

52. Forward recovery in a fast switching diode occurs during the time the current changes from ____________ to ____________ when switched with a switching voltage.

a. zero, a forward equilibrium value
b. a forward equilibrium value, zero
c. a forward equilibrium value, a designated recovery level
d. on, off

53. Forward recovery is measured between the ________% and ________% current points when the diode is switched with a ____________ switching voltage.

a. 90, 10, reverse
b. 50, 50, forward
c. 10, 90, forward
d. +50, -50, reverse

54. Reverse recovery is the time interval between the application of a ____________ switching voltage to a conducting diode, and the point at which reverse current reaches ____________.

a. reverse, designated recovery level
b. forward, designated recovery level
c. reverse, zero
d. forward, zero

55. Forward switching voltage is a ____________ voltage applied to a diodes cathode, or a ____________ voltage applied to a diodes anode.

   a. positive, negative
   b. negative, positive

56. The carriers recovered during reverse recovery time make up the diodes ______________.

   a. depletion region
   b. surface leakage
   c. contact resistance
   d. stored charge

57. Q_s is the symbol for diode stored charge, but a convenient unit of measure usually given in pico-coulombs per milliampere, is given the symbol _________.

   a. ϕ_q
   b. τ_q
   c. Q_q
   d. Φ_q

58. Stored charge varies directly as __________ and ______________.

   a. minority carrier lifetime, forward current
   b. minority carrier lifetime, reverse switching voltage
   c. forward current, reverse switching voltage
   d. forward switching voltage, minority carrier lifetime

59. The snap-off diode is designed for a ____________ stored charge per unit of forward current, and a fast ______________ time of the reverse recovery waveform.

   a. low, fall
   b. high, rise
   c. high, fall
   d. low, rise

60. The snap-off diode continues to conduct for the duration of the ____________ when switched with a reverse switching voltage.

   a. reverse switching voltage
   b. stored charge
   c, carrier cancellation time
   d. week

61.  is the symbol for a ________________ diode.

a. shockley
b. snap-off
c. back to back zener
d. four layer
e. either a or d

62.  is the symbol for a ____________, and A indicates the ______________.

a. snap-off, injector
b. four layer, control lead
c. shockley, shield
d. silicon control rectifier, gate
e. shockley, gate

ANSWERS TO SELF TEST

1.	b	22.	b	43.	a
2.	c	23.	c	44.	d
3.	a	24.	d	45.	c
4.	a	25.	b	46.	a
5.	d	26.	b	47.	d
6.	b	27.	a	48.	b
7.	d	28.	c	49.	a
8.	c	29.	b	50.	d
9.	a	30.	b	51.	e
10.	b	31.	a	52.	a
11.	d	32.	b	53.	c
12.	a	33.	c	54.	a
13.	b	34.	c	55.	b
14.	c	35.	c	56.	d
15.	c	36.	b	57.	b
16.	c	37.	a	58.	a
17.	a	38.	c	59.	c
18.	b	39.	a	60.	b
19.	a	40.	d	61.	e
20.	d	41.	b	62.	d
21.	a	42.	c		