Example 8.1: A balance scale consisting of a weightless rod has a mass of 0.1 kg on the right side 0.2 m from the pivot point. See Fig. below. (a) How far from the pivot point on the left must 0.4 kg be placed so that a balance is achieved? (b) If the O.4-kg mass is suddenly removed, what is the instantaneous rotational acceleration of the rod? (c) What is the instantaneous tangential acceleration of the O.l-kg mass when the O.4-kg mass is removed?

Solution:

(a) When a balance is achieved a = 0 and therefore ∑τ =0. On the right of the pivot point the force is m1g downward and the cross product r X F is into the paper or negative. On the left the force is m2g downward and the cross product r x F is out of the paper or positive.

(m2g)(x)sin 90° -(m1g)(0.2m)sin 90°=0

Solving for x, we have,

X=

=

= 0.05 m

(b) we have,

τ=Iα

α=

=

=

= 49 rad/sec2 clockwise

(c) We have,

aT=rα

= (0.2 m)(49 rad/sec2)

= 9.8 m/sec2

Example 8.2: A large wheel of radius 0.4 m and moment of inertia 1.2 kg-m2 pivoted at the center, is free to rotate without friction. A rope is wound around it and a 2-kg weight is attached to the rope (see Fig). When the weight has descended 1.5 m from its starting position (a) what is its downward velocity? (b) what is the rotational velocity of the wheel?

Solution:

(a) We may solve this problem by the conservation of energy, equating the initial potential energy of the weight to its conversion to kinetic energy of the weight and of the wheel.

Mgh=1/2mv2+1/2Iω2

The downward velocity v of the weight is equal to the tangential velocity at the rim of the wheel vT  therefore,

ω = vT /r =v/r

Substituting for ω,

Mgh=1/2mv2+1/2I v2/r2

We solve for the velocity v

V= = = 2.5 m/sec

(b) The answer to part (a) shows that any point on the rim of the wheel has a tangential velocity of VT = 2.5 m/sec. We convert this to rotational velocity of the wheel

ω = = = 6.2 rad/sec.

Example 8.4: Suppose the body of an ice skater has a moment of inertia I=4 kg-m2 and her arms have a mass of 5 kg each with the center of mass at 0.4 m from her body. She starts to turn at 0.5 rev/sec on the point of her skate with her arms outstretched. She then pulls her arms inward so that their center of mass is at the axis of her body,r=0. What will be her speed of rotation?

Solution:

Ioωo=Ifωf

(Ibody +Iarms)ωo=Ibody ωf

(Ibody+2mr2)ωo=Ibody ωf

Solving for ωf

ωf = = = 0.7rev/s.

Due to the small torque exerted by the ice, the angular momentumof a spinning skater is almost constant. As a result, when the skater pulls her arms inward, thus reducing its moment of inertia, her angular velocity increases.

Problem 8.1: A bicycle wheel of mass 2 kg and radius 0.32 m is spinning freely on its axle at 2 rev/sec. When you place your hand against the tire the wheel decelerates uniformly and comes to a stop in 8 sec. What was the torque of your hand against the wheel?

Solution:

Mass of wheel (m)=2 kg

Radius of wheel (r)= 0.32 m

Frequency (fo)= 2 rev/s

Time to stop(t)=8s

Torque (τ)= ?

We have ,

ωO=2πfo = 2 ×π ×2 = 4π rad/sec.

Also , I=mr2 = 2 × (0.32)2 = 0.20 kg/m2.

And,

ω = ωo­ + αt or, α = ωo / t (Here ω = 0 since stop at last)

α = 4π /8 =π/2 rad/sec2.

Finally, τ = Iα = 0.20 × π/2 = 0.32 Nm Ans.

Problem 8.2

Two masses,m1=1 kg and m2= 5 kg, are connected by a rigid rod of negligible weight (see Fig). The system is pivoted about point O. The gravitational forces act in the negative z direction. (a) Express the position vectors and the forces on the masses in terms of unit vectors and calculate the torque on the system. (b) What is the angular accelerationof the system at the instant shown in Fig.?

Solution:

M1=1 kg , r1=2m & M2=5 kg , r2=4m

Then,

Problem 8.7: A uniform wooden board of mass 20 kg rests on two supports as shown in Fig. A 30-kg steel block is placed to the right of support A. How far to the right of A can the steel block be placed without tipping the board?

Solution:

When balanced condition is achieved about B,

= 0 About B

i.e (m1g)r1 - (m2g)r2 = 0

i.e (m1g)r1 = (m2g)r2

i.e m1r1 =m2r2

i.e 20 × 3 = 30 × x

or, x = 2m.

Problem 8.18: A children's merry-go-round of radius 4 m and mass 100 kg has an 80-kg man standing at the rim. The merry-go-round coasts on a frictionless bearing at 0.2 rev/sec. The man walks inward 2m toward the center. What is the new rotational speed of the merry-go-round? What is the source of this energy? (The moment of inertia of a solid disk is I=1/2mr2).

Solution:

According to conservation of anglular momentum,

I1ω1 = I2ω2

i.e, (½ mr12 + mr1) 2πf1=(½ mr22 + mr2) 2πf2

i.e( ½ ×100× 42+ 80 × 42) 0.2 = ( ½ ×100× 42+ 80 × 22) f2 (since man moves 2m inward)

i.e f2 = 416/1120 =0.37 rev/ sec Ans.

Example 10.2: A given spring stretches 0.1 m when a force of 20 N pulls on it. A 2-kg block attached to it on a frictionless surface as in Fig. is pulled to the right 0.2 m and released .. (a) What is the frequency of oscillation of the block? (b) What is its velocity at the midpoint? (c) What is its acceleration at either end? (d) What are the velocity and acceleration when x = 0.12 m, on the block's first passing this point?

Solution:

First we must determine the spring constant k.

K= = = 200 N/m

(a) We may then calculate ω,

ω = = =10 rad/s.

As ω =2πv

V = = = 1.6 hz.

(b) The velocity is a maximum when x=0, that is, at the midpoint. Therefore, when a block is initially displaced a distance xo from its equilibrium position and then released, the amplitude of the motion A=xo.

V=v max = ±Aω = ± (0.2m) (10 rad/sec) = ± 2 m/sec.

(c) The acceleration is a maximum at the two extremes of the motion. Therefore,

Amax = ± Aω2 = ± (0.2m) (10 rad/sec2) = ± 20 m/sec.

(d) To determine the block's velocity and acceleration at some arbitrary value of x, we need to know the angle ωt at that position. In this problem, x= 0.12 m. We use the relation

X =A cosωt

ωt = arc cos = arc cos = 53°

v= -Aωsinωt = - (0.2m)(10 rad/sec) sin 53° = -1.6 m/sec (Moving toward the left).

A= -Aω2 cos ωt = - (0.2m)(10 rad/sec2)cos 53° = -12 m/sec2 (Accelerating toward the left).

Example 10.3: The block is released from a position of X1= A = 0.2 m as before. (a) What is its velocity at X2= 0.1 m? (b)What is its acceleration at this position?

Solution

1. The velocity at x2­ can be found with the conservation of energy equation,

kx12 + mv12 = kx22 + mv22

Solving for v2 , no1ting that v1 =0, we get

V2 = = =1.73 m/s

1. We may find the acceleration at this position by using newtons second law

F=ma

-kx=ma

A= - = - = -10m/s2

Problem 10.5: An oscillating block of mass 250 g takes 0.15 sec to move between the endpoints of the motion, which are 40 cm apart. (a) What is the frequency of the motion? (b) What is the amplitude of the motion? (c) What is the force constant of the spring?

Solution:

Mass (m) =250g =0.25 kg , Time(t)=0.15s , And 2A=40 I.e A=20 cm

Then

1. F = 1/t = 1/0.15 = 6.67 hz.
2. A = 20 cm.
3. K=mω2 = m(2πf)2 = 0.25 ×(2 ×π×6.67)2 =438.56 N/m Ans.

Problem 10.13: A block is oscillating with an amplitude of 20 cm. The spring constant is 150 N/m. (a) What is the energy of the system? (b) When the displacement is 5 cm, what is the kinetic energy of the block and the potential energy of the spring?

Solution:

Amplitude (A)= 20cm =0.2 m, K=150 N/m

1. ETotal = ½ kx2 = ½ × 150 ×(0.2)2 = 3 J
2. When x = 5cm =0.05m,

K.E= ½ mω2(A2-x2) = ½ k(A2-x2) = ½ ×150 ((0.2)2- (0.05)2) = 2.81 J

1. P.E = ½ kx2 = ½ × 150 ×(0.05)2 = 0.1875 J Ans.

Problem 10.18: A spring (k =200 N/m) is compressed 10 cm between two blocks of mass m1=1.5 kg and m2= 4.5 kg (see Fig). The spring is not connected to the blocks, and the table is frictionless . What are the velocities of the blocks after they are released and lose contact with the spring? Assume that the spring falls straight down to the table.

Solution:

Not provided!!

Example 14.1: A charge q1= 3×10-6 C is located at the origin of the x axis. A second charge q2= -5×10-6C is also on the x axis 4 m from the origin in the positive x direction . (a) Calculate the electric field at the midpoint P of the line joining the two charges. (b) At what point P' on that line is the resultant

field zero?

Solution:

1. Because q1 is positive, its electric field E1 at P is away from it, that is, in the positive x direction. The electric field E2 produced at point P by q2 is toward q2, that is, in the same direction as E1(See fig)



We have

|E1|= =9×109 = 6.75×103 N/C.

And |E2|= =9×109 = 11.25×103 N/C.

E= E1+E2 = 6.75×103 N/C + 11.25×103 N/C = 18×103 N/C.

1. From part (a), it is clear that the resultant E cannot be zero at any point between q1 and q2 because both E1 and E2 are in the same direction. Similarly E cannot be zero to the right of q2 because the magnitude of q2 is greater than q1 and the distance r is smaller for q2 than q1. E can only be zero to the left of q1 at some point P' to be found.

E=E1+E2=0

E­1= - E2

AND |E1|=|E2|

Or, =

Or, 3(x+4)2 =5x2

Or, 2x2- 24x-48=0

. . . x=13.75m or x=-1.75m(neglected).

Example 14.2: Three charge –q1=3×10­­-6C, q2= - 5×10­­-6C are nd –q3= - 8×10­­-6C are positioned on a straight line . Find the potential energy of the charges.

Solution:

We know,

Total potential (Etotal)=

=

= 4.43×10-2 J

Exercise 14.3: A potential difference of 100 V is established between the two plates, B being the high potential plate. A proton of charge q= 1.6 ×10-19C is released from plate B. What will be the velocity of the proton when it reaches plate A? The mass of the proton is 1.67 x 10-27kg.

Solution:

Because the proton is released with no initial velocity, Ek(B) is zero. we write

Ek(A) = q[V(B)-V(A)] = q ∆V

Or, = q ∆V

Solving for VA,

VA = = = 1.38 ×105 m/s.

Problem 14.6: Four charges of equal magnitude are placed at the corners of a square as shown in Fig. What is electric field at the center of the square, point O?

Solution:

|E1|= =9×109 along OC

|E2|= =9×109 along OD

|E3|= =9×109 along OA

|E4|= =9×109 along OB.

Total E at center is: (E1-E3) +(E2-E4) = 0+0=0 ans

Problem 14.8: Two large parallel plates are separated by a distance of 5 cm. The plates have equal but pposite charges that create an electric field in the region between the plates. An particle (q =3.2×10-19C,m= 6.68 x 10-27kg) is released from the positively charged plate, and it strikes the negatively charged plate 2 x 10-6sec later. Assuming that the electric field between the plates is uniform and perpendicular to the plates, what is the strength of the electric field?

Solution:

Distance(d)=s=5cm= 0.05m, Time (t)= 2 x 10-6sec, electric field(E)=?

= ……………………….. (i)

We have, i.e 0.05 = ½ a(2 x 10-6)2 (Since u =0 as it starts from rest)

Or, a =2.5 x 1010 m/sec2

Now equation (i) becomes

= 521.8 N =522 N Ans

Problem 14.21: An electron is placed midway between two fixed charges, q1= 2.5 × 10-10C and q2 = 5 ×10-10 C. If the charges are 1 m apart, what is the velocity of the electron when it reaches a point 10 cm from q2?

Solution:

Distance (d)= 0.5 - 0.1 =0.4m.

We know, v2-u2=2as or, v = (Here, u=0) ………………………. (i)

Force acting on electron, F=F2 - F1 =

Force = = 144×10-20  N.

Or , ma = 144×10-20  N. i.e a =( 144×10-20 /9.1 × 10-31 )= 15.8×1011  m/s.

Equation (i) becomes,

V = = 11.24×105 m/s Ans.

Example 16.1 : Assume that the electron in a hydrogen atom is essentially in a circular orbit of radius 0.5 x 10-10m, and rotates about the nucleus at the rate of 1014 times per second. What is the magnetic moment of the hydrogen atom due to the orbital motion of the electron?

Solution:

μ = area x current = πr2i

where i is the current due to a single electron. Because current is defined as the amount of charge passing per unit time, we may view the electron's orbit as a racetrack and ask how many times the electron passes a given point per second. The current is simply

i = e v

where v is the frequency of rotation and e is the magnitude of the charge of the electrons.

μ = πr2ev = π(0.5 ×10-10)2(1.6 × 10-19)(1014)

= 1.26 × 10-25 Am2.

Therefore, the hydrogen atom is essentially a small bar magnet and will behave as such in a magnetic field.

Example 16.2: A current of 50 A is established in a slab of copper 0.5 cm thick and 2 cm wide. The slab is placed in a magnetic field B of 1.5 T. The magnetic field is perpendicular to the plane of the slab and to the current. The free electron concentration in copper is 8.4 x 1028 electrons/m3 . What will be the magnitude of the Hall voltage across the width of the slab?

Solution:

VH = = = 1.12 × 10-6 V.

Problem 16.1

What force is experienced by a wire of length l = 0.08 m at an angle of 20° to the magnetic field direction carrying a current of 2 A in a magnetic field of 1.4 T?

Solution:

We have ,

F = BILsinӨ = 1.4 × 2 × 0.08 × sin 20° = 7.6×10-2 N. Ans

Problem 16.2: The earth's magnetic field at the equator is 4 x 10- 5 T and is parallel to the surface of the earth in the south-north direction. (Note that the earth' s geographic north pole is the magnetic south pole.) A wire 2 m long of mass m = 9 g is suspended by a string. The wire is also parallel to the earth's surface and carries a current of 150 A in the east-west direction. (a) What is the tension on the string? (b) What would be the tension if the current was in the west-east direction?

Solution:

1. T = mg + BIL = 9×10-3 × 9.8 + 4×10-5 × 150 ×2 =0.0882 +0.012 =0.1002 N
2. T = mg - BIL = 9×10-3 × 9.8 - 4×10-5 × 150 ×2 =0.0882 -0.012 =0.076 N ANS.

Problem 16.12

A proton is moving with a velocity v =( 3 × 105 I + 7 × 105 k) m/sec in a region where there is a magnetic field B = 0.4 j T. What is the force experienced by the proton?

Solution:

=

Problem 16.13: A proton is accelerated through a potential difference of 200 V. It then enters a region where there is a magnetic field B = 0.5 T. The magnetic field is perpendicular to the direction of motion of the proton. What is the force experienced by the proton?

Solution:

Force (f) =BqVsinӨ = 0.5 × 1.6 × 10-19 × 200 × Sin(90°) = 1.6 × 10-17 N.

Example 18.2: After being excited, the electron of a hydrogen atom eventually falls back to the ground state. This can take place in one jump or in a series of jumps, the electron falling into lower excited states before it ends up in the ground state. Consider a hydrogen atom that has been raised to the second excited state, that is, n= 3. Calculate the different photon energies that may be emitted as the atom returns to the ground state.

Solution:

The possible transition are shown in figure:

We have,

Problem 18.1: Calculate the shortest and the longest wave length of the Balmer series of hydrogen.

For shortest n1=2 and n2=infinity. And for longest wavelength n1=2 and n2=3. And calculate.

Problem 18.2: What are (a) the energy, (b) the momentum, and (c) the wavelength of the photon that is emitted when a hydrogen atom undergoes a transition from the state n = 3 to n = 1? (The momentum of the photon is given by hf/c).

Problem 18.3: The shortest wavelength of the Paschen series from hydrogen is 8204 Ao. From this fact, calculate the Rydberg constant.

Problem 18.19: The ground-state and the first excited-state energies of potassium atoms are -4.3 eV and -2.7eV, respectively. If we use potassium vapor in the Franck-Hertz experiment, at what voltages would we see drops in the plot of current versus voltage?

Example 19.1: A beam of monochromatic neutrons is incident on a KCl crystal with lattice spacing of 3.14 Ao. The first-order diffraction maximum is observed when the angle Ө between the incident beam and the atomic planes is 37°. What is the kinetic energy of the neutrons?

Solution:

Using the Bragg condition, with n =1, we can find the wavelength of the neutron beam.

λ =2dsinӨ = 2 x 3.14sin 37° = 3.78A°

from de-Broglie’s hypothesis, the momentum of the neutron is

p = = = 1.75 × 10-24 kg-m/s.

The kinetic energy of the neutron will be

E = = = = 9.21 × 10-22 J = 5.75 × 103 eV.

Problem 19.2: The de Broglie wavelength of a proton is 10- 13m. (a) What is the speed of the proton? (b)Through what potential difference must the proton be accelerated to acquire such a speed?

Solution:

Wavelength(λ) = 10- 13m. mass of proton=1.67×10-27 kg.

Then , λ= i.e, v=3.964 × 106 m/s2.

And thus, V= 8.2 × 104 volt.

Problem 19.7: An α particle is emitted from a nucleus with an energy of 5 MeV (5 x 106 eV). Calculate the wavelength of an α particle with such energy and compare it with the size of the emitting nucleus that has a radius of 8 × 10-15m.

Solution:

Here, Ek= 5×106 ev = 5×106 ×1.6×10-19 = 8×1013  J. Mα= 2mp=2×1.6×10-27= 3.34×10-27 kg.

λ= = …………………

Problem 19.11: In neutron spectroscopy a beam of monoenergetic neutrons is obtained by reflecting reactor neutrons from a beryllium crystal. If the separation between the atomic planes of the beryllium crystal is 0.732 A°, what is the angle between the incident neutron beam and the atomic planes that will yield a monochromatic beam of neutrons of wavelength 0.1 A°?

Solution :

Here , d=0.743 ×10-10m , λ= 0.1×10-10m. n=1 for first order.

We have,

nλ =2dsinӨ I.e sinӨ=nλ/2d

Ө= sin-1(0.089)= 3.9° ans.

Problem 19.16: A small particle of mass 10-6g moves along x axis ; its speed is uncertain by 10-6 m/sec. (a) What is the uncertainty in the x coordinate of the particle? (b) Repeat the calculation for an electron assuming that the uncertainty in its velocity is also 10-6 m/sec.

Solution:

M=10-6g =10-9 kg, ∆v=10-6m/s , ∆p=m∆v =10-9×10-6 = 10-15 kgm/s.

1. ∆x= ? we have, ∆x.∆p = 🡪 ∆x= 1.05 ×10-19 m ans.

(b) For electrons, M=9.1×10-31 kg, ∆v=10-6m/s , ∆p=m∆v =9.1×10-31 ×10-6 = 9.1×10-37 kgm/s.

∆x= ? we have, ∆x.∆p = 🡪 ∆x= 116 m ans.

Problem 19.19: The uncertainty in the position of a particle is equal to the de Broglie wavelength of the particle. Calculate the uncertainty in the velocity of the particle in terms of the velocity of the de Broglie wave associated with the particle.

Solution:

∆x = and , ∆x.∆p = i.e m∆v= i.e ∆v=v/2π ans.

Example 20.2: Consider a particle in the ground state, that is, one represented by the wavefunction. What is (a) the average position, (b) the average momentum, and (c) the average energy of such a particle?



Solution:

1. The average position is given by

Which in the present case becomes

From the integration table, we get

This result makes physical sense and would have been predicted by looking at a graph of the probability density which is plotted in Fig. It is clear that the probability of finding the particle on the left side of the well is the same as the probability of finding it on the right side. The average position is therefore the midpoint x= a/2, which is the result found in the preceding calculation. This result is true not only for n = 1 but for all n's. For example, the square of the eigenfunctions will be symmetric about the midpoint of the well.

1. The average value of momentum can be found by following ways:

This result also makes physical sense. The particle is moving back and forth between the walls of the well. The probability of finding the particle moving toward the right is the same as the probability

of finding it moving toward the left. Thus the average value of the momentum has to be zero.

1. The average value of energy E can be calculated as follows:

In the last step, we made use of the fact that = 1. The result should come as no surprise. In this case the particle has a well-defined energy E = Eo. We expect therefore that the average value will be the actual value.

Problem 20.1: Show by direct substitution into the time-dependent Schrodinger equation for the free particle, that Ψ*(x, t)* = *A cos(kx* - *wt)* is not a solution.

Problem 20.2: Show by direct substitution that the wavefunction Ψ*(x, t)* = *A* cos *kx e- iwt* satisfies the timedependent Schrodinger equation for the free particle.

Problem 20.3: Explain why the following eigenfunctions are not acceptable solutions of the Schrodinger equation

(a)  *(x)* = 0 for *x* ≤ 0 ,  *(x)* = *A* cos *kx* for *x* ≥ 0

(b)  *(x)* = *A*

(c)  *(x)* = *A* In *kx*

Problem 20.12: What is the probability of finding a particle in a well of width *a* at a position *a/4* from the wall if *n* = I, if *n* = 2, if *n* = 3. Use the normalized wavefunctions Ψ *(x, t)* = *(2/a)1I2* sin *wrrx/a e - iEtih .*

Example 21.2: A beam of hydrogen atoms is used in a Stern-Gerlach type experiment. The atoms emerge from the oven with a velocity *v* = 104 m/sec. They enter a region 20 cm long where there is a magnetic field gradient *dB / dz* = 3x*104 T/m.* The field gradient is perpendicular to the incident velocity of the

atoms. The mass of the hydrogen atom is 1.67 x 10-27 kg. What is the separation of the two components of the beam as they emerge from the magnet?

Solution: In the ground state, hydrogen atoms have no net *orbital* magnetic dipole moment. The only dipole moment is the one associated with the *spin* of the electron in the 1s state, that is, *μs = -|e| /* S, where *m* is the mass of the electron. From our previous discussion of the Stern-Gerlach experiment,

Fz = μs = sz = ±

We can use Newton's second law to find the acceleration *az* of the hydrogen atoms as they traverse the magnet.

*az = =* = = m/s2.

The deflection of each component in the direction of the force (z axis) will be

∆z=azt2

where *t* is the time that the atoms spend in the magnet. This time can be found by dividing the length of the magnet by the incident velocity of the atoms.

Therefore,

t = 0.20 m = 2 x 10-5 sec

∆z = x 1.65 X 108 x 4 x 10-10 = 3.3 X 10-2  m = 3.3 cm

Because of the two possible values for *ms ,* some atoms will be deflected upward and some downward. Therefore, the separation between the two components of the beam will be 2 ∆z or 6.6 cm.

Problem 21.3: In the Bohr model of the hydrogen atom, the electron is assumed to move in circular orbits around the proton, that is, the motion takes place in a plane that we can call the *x-y* plane. Use the uncertainty principle in the z direction, that is, *∆p*z ∆z ≥ and the fact that ≥ (∆Pz)2 to show that the motion of the electron cannot be planar motion.

Problem 21.6: (a) How many atomic states are there in hydrogen with *n* = 3? (b) How are they distributed among the subshells? Label each state with the appropriate set of quantum numbers *n, I, ml, ms.* (c)Show that the number of states in a shell, that is, states having the same *n,* is given by *2n2 . (Hint:*1 + 2 + 3 + .. . + *n* = *n(n* + *1)/2.)*

Problem 22.1: Copper has a face-centered cubic structure witha one-atom basis. The density of copper is 8.96 *g/cm3* and its atomic weight is 63.5 g/mole. What is the length of the unit cube of the structure?

Problem 22.3: Assuming that atoms in a crystal structure are arranged as close-packed spheres, what is the ratio of the volume of the atoms to the volume available for the simple cubic structure? Assume a one-atom basis.

Problem 22.4: Repeat Problem 22.3 for the body-centered cubic structure.

Problem 22.5: Repeat Problem 22.3 for the face-centered cubic structure.

Problem 22.9: The dissociation energy of the KF molecule is 5.12 eV. The ionization energy for K is 4.34 eV, and the electron affinity of F is 4.07 eV. What is the equilibrium separation constant for the KF molecule?

Example 23.1: Consider a copper wire of cross-sectional area *A* = 1 mm2 carrying a current i = 1 amp. What is the drift velocity *Vd* of the electrons? Cu is monovalent, that is, there is one free electron per atom. The density and the molecular weight of Cu are 9 *g/cm3* and 64 g/mole, respectively.

Solution:

We know,

Vd =

The current density J is given by,

J== = 106  amp/m2.

Because copper is monovalent, the number of free electrons per unit volume N is equal to the number of atoms per unit volume NAtoms. The latter can be found as follows :

NAtoms= (number of moles/cm3) x (number of atoms/mole)

The number of atoms per mole is given by Avogadro's number N A = 6.02 X 1023 atoms/mole. Thus,

N=NAtoms = ×(6.023 × 1023)= 8.4 × 1023 atoms/cm3  =8.4 × 1028 atoms/m3.

Substituting for *J* and N into the expression for Vd we obtain,

Vd = = 7 × 10-5 m/s.

Example 23.2: The number of free electrons in copper is 8.4 x 1028 electrons/m3 • (a) Calculate the Fermi energy for Cu. (b) At what temperature *Tf* will the average thermal energy *kB Tf* of a gas be equal to that energy?

Solution:

1. Substituting for the different parameters we obtain,

Ef(0) = ×(3 × 8.4 × 1028 × π2)2/3 = 11.1 × 10-19 J =6.95 eV.

(b) We can equate this energy to *kB Tf* to find the temperature at which the average thermal energy would be equal to the Fermi energy of Cu.

Tf = = = 80500 K.

This result illustrates the profound changes introduced by the QMFE model. For a classical electron gas to have thermal energies similar to those that a quantum mechanical electron gas has at *T* = 0 K, the temperature of copper should be about 60 times higher than its melting temperature, 1356 K.

Problem 24.6: The energy gaps of some alkali halides are KCl = 7.6 eV, KBr = 6.3 eV, KI = 5.6 eV. Which

of these are transparent to visible light? At what wavelength does each become opaque?

Problem 24.8: The density of aluminum is 2.70 *g/cm3* and itsmolecular weight is 26.98 *g/mole.* (a) Calculate the Fermi energy. (b) If the experimental value of *EF* is 12 eV, what is the electron effective mass in aluminum? Aluminum is trivalent.

Example 25.2: A sample of Si is doped with phosphorous. The donor impurity level lies 0.045 eV below the bottom of the conduction band. At *T* = 300 K, EF is 0.010 eV above the donor level. Calculate (a) the impurity concentration, (b) the number of ionized impurities, (c) the free electron concentration, and (d) the hole concentration. (For Si, *EG* = 1.100 eV, *me\**= 0.31 *m, mh\** = 0.38 *m).*

Solution:

We have

= + ND

And

Nc = == 4.39 × 1024 m-3.

And

Nv = = = 5.95 × 1024 m-3.

Substituting for *NC, Nv, EF,* and ED(keep in mind that energies are measured from the top of the valence band), we get

4.39 × 1024 = 5.95 × 1024 + ND

OR, 1.08 × 1024 = 1.88 ×106 + ND(0.40)

ND = 2.7 × 1024 m-3.

1. The number of ionized impurities is given by ,

ND+ =

= 2.7 × 1024

=1.08 × 1024 m-3

(c) The free electron concentration , which from part (a) of this example is

*Ne* = 1.08 × 1024 m-3

(d) The hole density is found to be,

Nh=1.88 × 106 m-3.

Problem 25.1:The band gap in pure germanium is *Eg =* 0.67 eV. (a) Calculate the number of electrons per

unit volume in the conduction band at 250 K, 300 K, and at 350 K. (b) Do the same for silicon assuming *Eg* = 1.1 e V. The effective mass of the electrons in germanium is 0.12 *m* and in silicon 0.31 *m,* where *m* is the free electron mass.

Problem 25.2: Suppose that the effective mass of holes in a material is four times that of electrons. At what temperature would the Fermi level be shifted by 10% from the middle of the forbidden energy gap? Let *Eg* = 1 eV.

Problem 25.3: The energy gap in germanium is 0.67 eV. The electron and the hole effective masses are 0.12 *m* and *0.23 m,* respectively, where *m* is the free electron mass. Calculate (a) the Fermi energy, (b) the electron density, and (c) the hole density, at *T* = 300 K.

Problem 25.13: A certain intrinsic semiconductor has a band gap *Eg* = 0.2 eVe Measurement shows that it has a resistivity at room temperature (300 K) of 0.3 Ω-m. What would you predict its resistivity to be at 350 K?

Problem 25.16: The energy gap in silicon is 1.1 eV, whereas in diamond it is 6 eVe What conclusion can you draw about the transparency of the two materials to visible light (4000 Ao to 7000 A0)?

Problem 26.1: The currentthrough a *p-n* junction is 1 x 10-8 A when a reverse bias voltage of 10 V is applied across the junction at *T* = 300 K. What will be the current through the diode when a forward bias voltage of (a) 0.1 V, (b) 0.3 V, and (c) 0.5 V is applied?

Problem 26.2: In the ideal diode the reverse saturation current should be as small as possible. Considering the fact that *Eg* for Si is 1.1 eV and *Eg* for Ge is 0.67 eV, which material is better suited for the fabrication of *p-n* junction diodes?

Problem 26.3: The reverse saturation current of a silicon diode is io = 5 X 10-9 A The voltage across that diode when forward biased is 0.45 V. (a) What is the current through the diode at *T* = 27°C? (b) If the voltage across the diode is held constant, and we assume that io does not change with temperature, what is the current through the diode at *T* = 47°C?

Problem 26.4: In Problem 26.3 we assumed that the reverse saturation current io remains constant when the temperature changes. (a) Show that this assumption is highly incorrect by calculating io at *T* = 47°C when io = 5 X 10-9 A at 27°C. Assume that the Fermi level on the *p* side of the junction is 1 e V below the bottom of the conduction band. (b) If the voltage across the forward biased diode is 0.45 V, as in Problem 26.3, what is the current through the diode at *T* = 47°C?

Problem 26.5: The reverse saturation current of a silicon diode doubles when the temperature changes from 27°C to 33°C. What is the position of the Fermi level on the *p* side of the junction?

Problem 27.1: Make the appropriate truth tables to prove the following distributive law of boolean algebra:

A (B + C) = AB + AC

Problem 27.6: Analyze the circuit shown in Fig. Determine the logic function performed by the circuit

by making and justifying the appropriate truth table.

Problem 27.9: (a) Find the truth table for the circuit shown in Fig. What logic function does the circuit perform? (b) What logic function will the circuit perform if the constant + 5 V input to the first two gates is changed to ground potential?

Problem 27.10: (a) Find the truth table for the circuit of Fig.. What logic function does the circuit perform? (b) What logic function will the circuit perform if the common grounded input to the first two NOR gates is changed to + 5 V?