Baha University — Second Term 2012/2013
Banha Faculty of Engineering — First Year (corrective)
Department of Basic Engineering Sciences

Solutions of the Questions For Written Term-Examination

Subject: Physics B131 — Allowed Time: 3 Hours

Answer all questions — No. of Questiona:5 — No. of pages:2

Solution to Question 1

a) Sinusoidal waves 5 cm in amplitude are to be transmitted along a string that has a linear mass density of 4×10^{-2} kg/m. If the source can deliver a maximum power of 300 W and the string is under tension of 100 N, what is the highest vibrational frequency at which the source can operate?

Answer

$A = 5$ cm $= 0.05$ m
$\mu = 0.04$ kg/m
$P = 300$ W
$F = 100$ N
$V = \sqrt{F/\mu} = \sqrt{100/0.04} = 50$ mls
$P = ½ \mu v \omega^2 A^2$
$\omega = (1/A)\sqrt{2P/\mu v} = (1/0.05)\sqrt{2*300/0.04*50}$
$= 346.4$ rad/s
$f = \omega/2\pi = 346.4/2\pi = 55.2$ Hz

b) How are beats produced? Derive an expression for the equation of the beats. Determine the beat frequency.

Answer

The beats are generated as a superposition of two sound waves having slightly different frequencies.
Consider two waves of the same amplitude and wavelength faving frequencies f_1 and f_2 passing through a common point which can be taken as x = 0.

$y_1 = A \cos \omega_1 t = A \cos 2\pi f_1 t$
$y_2 = A \cos \omega_2 t = A \cos 2\pi f_2 t$

Applying the principle of superposition, the resulting wave is

$y = y_1 + y_2$
$= A [\cos 2\pi f_1 t + \cos 2\pi f_2 t]$
$= 2A \cos 2\pi[(f_1 - f_2)/2]\, t \cos 2\pi[(f_1 + f_2)/2]\, t$

The amplitude of the beats is $2A \cos 2\pi[(f_1 - f_2)/2]\, t$.
This amplitude has two peaks per cycle, that is, there are two beats per cyle.
Since the frequency of the amplitude which is the number of cycles per second is $(f_1 - f_2)/2$, then the beat frequency is
$f_b = 2*(f_1 - f_2)/2 = f_1 - f_2$

Solution to Question 2

a) A train passes a passenger platform at a constant speed of 40 m/s. The train horn is sounded at a frequency of 320 Hz. (i) What change in frequency is detected by a person on the platform as the train passes? (ii) What wavelength is detected by a person on the platform as the train approaches? [velocity of sound = 343 m/s]

Answer

(i) $v_s = 40$ mls

$f_o = 320$ Hz

$f' = f_o \dfrac{\mathbf{v}}{\mathbf{v}+\mathbf{v}_s} = 320\dfrac{343}{343+40} = 288.84$ Hz

(ii) $\lambda' = \lambda - v_s/f_o = v/f_o - v_s/f_o = (v - v_s)/f_o$

$= (343 - 40)/320 = 0.95$ m

b) Derive an expression for the intensity of interference pattern on the screen of Young's double slit interference experiment.

Answer

In the Young's double slit interference experiment, assume that
slit separation distance = d
distance from slits to screen = L
wavelength of monochromatic light = λ
Any point on the screen receives light waves from each slit.
The path difference between the two waves is

$\delta = |r_2 - r_1| = d \sin\theta$

The phase difference $\Phi = (2\pi/\lambda)\delta = (2\pi/\lambda)\, d \sin\theta$

The electric field wave from slit 1 reaching a point P (at x = 0) on screen

$E_1 = E_o \sin \omega t$

The electric field wave from slit 2 reaching the same point P (at x = 0) on screen

$E_2 = E_o \sin (\omega t + \Phi)$

Applying the principle of superposition, the resulting wave is

$E = E_1 + E_2$

$= E_o [\sin (\omega t + \Phi) + \sin \omega t]$

$= 2 E_o \cos \Phi/2 \sin (\omega t + \Phi/2)$

The intensity of light is directly proportional to the square of the electric field

$I \propto E^2 = 4 E_o^2 \cos^2 \Phi/2 \sin^2 (\omega t + \Phi/2)$

The average intensity is then

$I \propto 2 E_o^2 \cos^2 \Phi/2 \qquad (1)$

Where the average of $\sin^2 (\omega t + \Phi/2)$ is ½.

The intensity at the center of the experiment where $\Phi = 0$ is

$I_o \propto 2 E_o^2 \qquad (2)$

Dividing equation (2) by equation (1), then the intensity
$I = 2 E_o^2 \cos^2 \Phi/2$
Bright fringes when the intensity is maximum.
$\cos \Phi/2 = 1$
$\Phi = 2m\pi$
$(2\pi/\lambda)d\sin\theta = 2m\pi$
$d\sin\theta = m \lambda$
$dy/L = m \lambda$
$y_m = m \lambda L/d$

Dark fringes when the intensity is minimum.
$\cos \Phi/2 = 0$
$\Phi = (2m + 1)\pi$
$(2\pi/\lambda)d\sin\theta = (2m + 1)\pi$
$d\sin\theta = (m + ½) \lambda$
$dy/L = (m + ½) \lambda$
$y_m = (m + 1/2) \lambda L/d$

Answer to Question 3

a) a material having an index of refraction of 1.3 is used to coat a piece of glass of index 1.5. What should be the minimum thickness of this film to minimize reflection of 500 nm light?

Answer

The state is air – film – glassl.
Index of refraction of film n = 1.3
Wavelength of light λ = 500 nm
If the film thickness is t,
the condition for minimum reflections is
$2nt = (m + ½) \lambda$
For minimum thickness m = 0,
Then, $t_{min} = \lambda/4n = 500\text{x}10^{-9}/4*1.3 = 9.62\text{x}10^{-8}$ m = 96.2 nm

b) A diffraction pattern is formed on a screen 120 cm away from a 0.4 mm wide slit. Monochromatic light of wavelength 546 nm is used. Calculate the fractional intensity I/I_o at a point on the screen 4.1 mm from the center of the principal maximum.

Answer

L = 120 cm
a = 0.4 mm
λ = 546 nm
y = 4.1 mm
Phase difference $\beta = (2\pi/\lambda)\ a \sin\theta = (2\pi/\lambda)\ ay/L$
$= (2\pi)*(0.4\text{x}10^{-3})*(4.1\text{x}10^{-3})/(546\text{x}10^{-9})*(1.2)$
$= 15.73$ rad

The fractional intensity $I/I_o = \sin^2\beta/\beta^2 = \sin^2(15.73)/(15.73)^2$
$= 1.96\times10^{-6}$

Answer to Question 4

a) One mole of an ideal gas does 3000 J of work on its surroundings as it expands isothermally to a final pressure of 1 atm. and volume of 25 L. Determine (i) the initial volume and (ii) the temperature of the gas. [R = 8.31 J/mol.K] [1 atm = $1.0135\ x10^5$ Pa]

Answer

Number of moles n = 1
Work done by the gas W = 3000 J
The gas expands isothermally.
Final pressure p_f = 1 atm
Final volume V_i = 25 L
(i) For isothermal expansion, the work done

$$W = nRT\ \ln(V_f/V_i)$$

The gas is ideal, then $p_fV_f = nRT$
Then, $W = p_fV_f\ \ln(V_f/V_i)$

$$\ln(V_f/V_i) = w/\ p_fV_f = 3000/(1.0135\text{x}10^5)*(25\text{x}10^{-3})$$
$$= 1.184$$
$$V_f/V_i = e^{W/pfVf} = e^{1.184} = 3.27$$
$$V_i = 25L/3.27 = 7.65\ L$$

(ii) The temperature $T = p_fV_f/nR = (1.0135\text{x}10^5)*(25\text{x}10^{-3})/8.31$
$= 304.9$ K

b) A 2 mole of diatomic ideal gas expands adiabatically from pressure of 5 atm and a volume of 12 L to a final volume of 30 L. (i) What are the final pressure, the initial temperature and the final temperature? (ii) Find Q, W and ΔU.

Answer

Number of moles n = 2
The gas is diatomic and expands adiabatically.
Initial pressure P_i = 5 atm.
Initial volume V_i = 12 L
Final volume V_f = 30 L
(i) Since the process is adiabatically, and for $\gamma = 1.4$,

$$p_iV_i^{\gamma} = p_fV_f^{\gamma}$$
$$p_f = p_i(V_i/V_f)^{\gamma} = 5\ (12/30)^{1.4} = 1.386\ \text{atm}$$

Since the gas is ideal,
The initial temperature $T_i = p_iV_i/nR$
$= (5\text{x}1.0135\text{x}10^5)*(12\text{x}10^{-3})/2*8.31$
$= 365.9$ K
The final temperature $T_f = p_fV_f/nR$

$= (1.386 \times 1.0135 \times 10^5)*(30 \times 10^{-3})/2*8.31$
$= 253.56$ K

Answer to Question 5

a) A Carnot engine has a power output of 150 kW. The engine operates between two reservoirs at 20°C and 500°C. (i) How much energy does it takes in per hour? (ii) How much energy is lost per hour in its exhaust?

Answer

Output power W = 150 kW

$T_C = 20^oC = 20 + 273 = 293$ K

$T_H = 500^oC = 500 + 273 = 773$ K

(i) Efficiency $e = 1 - T_C/ T_H = 1 – 293/773 = 0.621$

$e = W/Q_H$

$Q_H = W/e = 150k/0.621 = 241.55$ W

Energy taken per hour = 241.55*60*60 = 868,580 Joule

(ii) $Q_C/Q_H = T_C/T_H$

$Q_C = Q_H\, T_C/T_H = (241.55)*(293/773) = 91.56$ W

Energy lost per hour = 91.56*60*60 = 329,608 Joule

b) Choose the correct answer and **justify** your results

(1) The speed of wave on a string can be increased by increasing

(a) the wave number (b) the angular frequency

(c) the tension in the string (d) the mass linear density

Because $v = \sqrt{F/\mu}$

So increasing the tension force F will increase the speed of the wave v.

(2) An observer is 320 m away from a point sound source. The observer measures an intensity of 73.9 dB. What is the power delivered to the medium by the sound source?

(a) 31.58 W (b) 58.43 W (c) 2.45×10^{-5} W (d) not stated

Sound level $\beta = 10 \log I/I_o$

$\log I/I_o = \beta/10 = 73.9/10 = 7.39$

$I/I_o = 2.455 \times 10^7$

$I = 2.455 \times 10^7\, I_o = 2.455 \times 10^7 * 1 \times 10^{-12}$

$= 2.455 \times 10^{-}5\ W/m^2$

Power $P = I*(4\pi r^2)$

$= 2.455 \times 10^{-5}*(4\pi(320)^2)$

$= 31.59$ W

(3) A middle C note has a frequency of 244 Hz. What is the shortest open-closed pipe that produced this note?
(a) 54.67 cm   (b) 70.31 cm   **<u>(c) 35.15 cm</u>**   (d) not stated
The resonant frequencies

$f_m = mv/4L$

where m is an odd number.

$L = mv/4\ f_m$

The shortest pipe is when m = 1.

$L = v/4f_1 = 343/4*244 = 0.3514\ m = 31.14\ cm$

(4) A Young double slit interference experiment is carried out with a pair of slits separated by 0.03 mm. The slits are 1.2 m from a screen. The second order maximum is measured to be 4.5 cm from the center line. What is the wavelength of light?
<u>(a) 562.5 nm</u>   (b) 654.8 nm   (c) 347.6 nm   (d) not stated
d = 0.03 mm
L = 1.2 m
$y_2 = 4.5$ cm
The positions of the maximum intensity:
$y_m = m\lambda L/d$
$y_2 = 2\ \lambda L/d$
The wavelength $\lambda = y_2 d/2L = (4.5\text{x}10^{-2})*(0.03\text{x}10^{-3})/2*(1.2)$

$= 5.625\text{x}10^{-7}\ m = 562.5\ nm$

(5) A diffraction grating has 10000 lines per centimeter. What is the angle of first order maximum if light of wavelength 600 nm illuminates the grating?
(a) 45.78^o **<u>(b) 36.86^o</u>**   (c) 23.58^o (d) not stated
The slit separation $d = 10^{-2}/10000 = 10^{-6}$ m
$d \sin\theta = m\lambda$
$\sin\theta = m\lambda/d = (1)(600\text{x}10^{-9})/10^{-6} = 0.6$
$\theta = 38.87^o$

(6) What is work done by a constant pressure process at $3.324\text{x}10^4$ Pa to compress a gas from 0.1 m^3 to 0.02 m^3.
<u>(a) - 2659 J</u>   (b) - 6783 J   (c) - 9543 J   (d) not stated
$W = p(V_f - V_i) = (3.324\text{x}10^4)*(0.02 - 0.1)$

$= -\ 2659.2$ Joule

(7) The efficiency of any heat engine is given by
(a) $\frac{T_2 - T_1}{T_2}$ **<u>(b)</u>** $\underline{\frac{Q_2 - Q_1}{Q_2}}$ (c) $\frac{T_1 - T_2}{T_2}$ (d) $\frac{Q_1 - Q_2}{Q_1}$

Q_2 is the heat taken in at high temperature T_2

Q_1 is the heat lost at low temperature T_1
The efficiency $e = W/Q_1$
Since the heat engine is operating in a cycle, $\Delta U = 0$.
From the first law: $Q = \Delta U + W$
Then $W = Q = Q_2 - Q_1$
The efficiency $e = W/Q_1 = (Q_2 - Q_1)/Q_1$

(8) A window is made of glass that has a surface area of 1600 cm^2 and a thickness of 3 mm. Inside the house the temperature is 21.1°C and outside temperature is 32.2°C. What is the rate of heat transfer through the window? [For glass: k = 0.8 W/m.K]
(a) 234.5 W (b) 657.5 W **(c) 473.6 W** (d) not stated
$A = 1600\ cm^2$
$L = 3\ mm$
$T_C = 21.1^oC$
$T_H = 32.2^oC$
The rate of heat transfer $H = kA(T_H - T_C)/L$
$$H = (0.8)*(1600\times10^{-4})*(32.2 - 21.1)/3\times10^{-3}$$
$$= 473.6\ W$$
