Electromagnetic Waves

Basic Problems

1. A microwave oven works with electromagnetic waves of 2.45 GHz. Is there any danger of standing waves in the appliance?
2. The antennas used in mobile phones usually have a length of a quarter of a wavelength. How long are the antennas for the 3G frequency band (1'900 MHz)?
3. What would be the magnitude of the electric field vector in an electromagnetic wave whose magnetic field has the same magnitude as the horizontal component of the terrestrial magnetic field in Zurich?
4. Calculate the speed of low frequency electromagnetic waves in water. (Hint: Look up the value for the dielectric constant of water). Compare the result with the value for visible light.
5. What is the wavelength of red light (650 nm) in acrylic glass (Plexiglas M222)?
6. A laser beam with a power of 3.5 mW has a diameter of 1.3 mm. Calculate the magnitudes of the electric and the magnetic field vector.
7. The magnetic field's amplitude of an electromagnetic wave propagating along the positive y-axis can be described by the vector (2.5|0|0) μT. Calculate the electric field's magnitude and the Poynting vector.
8. Microwaves are diffracted at a double slit with slit separation 8.5 cm. The first bright fringe is measured at an angle of 25° to the incoming waves. Calculate the frequency of the microwaves.
9. The light of a He-Ne laser (632.8 nm) hits a grating with 500 lines/cm. The resulting pattern is observed on a screen 4.5 m from the grating. Calculate the positions of the first three principal maxima.
10. The spectrum of a sodium lamp ("Formeln und Tafeln", T 176) is analysed with a spectrometer using a grating with 5000 lines/mm. Calculate the distance between the two yellow lines on a screen 4.5 m away.
11. In order to measure the thickness of a sheet of paper you determine the diffraction pattern of green laser light (532 nm) hitting a paper strip on one of its edges. The first minima on a screen 2.5 m away are at 1.1 cm from the zeroth maximum. Calculate the thickness of the paper.
12. In his painting „Un dimanche après-midi à la Grande Jatte", pointillist painter Georges Seurat used coloured dots 2 mm apart. How far from the painting do the points start to dissolve into continuous areas? You may assume a diameter of 4 mm for the pupil of a human eye. Why and how does this minimum distance depend on the illumination in the room?

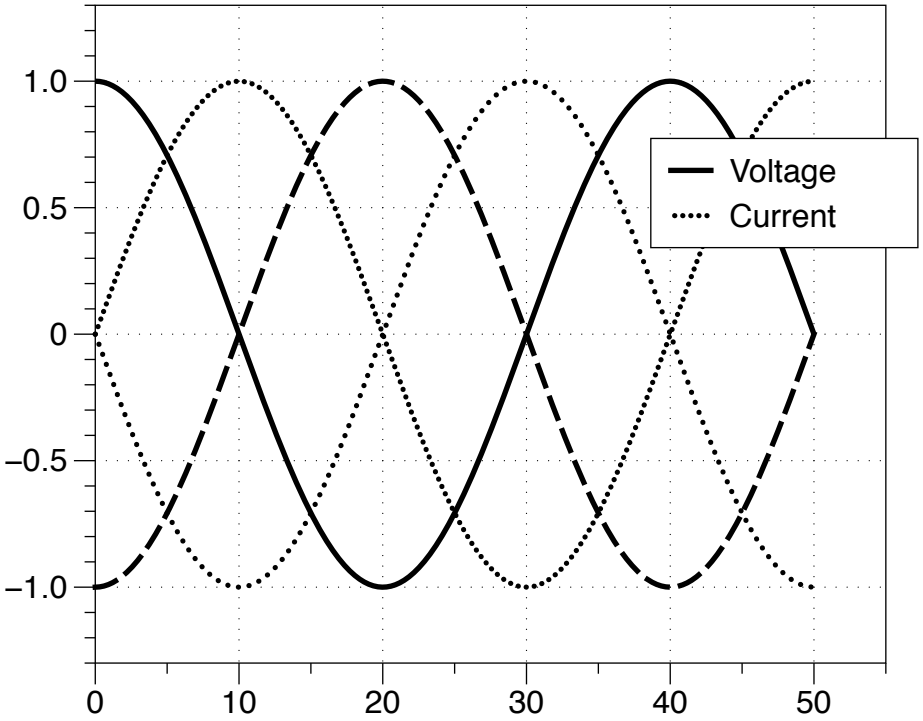
Supplementary Problems

13. Two 50 cm long wires run parallel to each other. They are connected on one end. When brought close to a radio transmitter, a voltage antinode can be found at 10 cm from the connected ends.
    a) Sketch the voltage and current amplitudes along the wires.
    b) Calculate the transmitter's frequency.
14. On a clear day you happen to have the opportunity to float in a hot air balloon at a height of 3.5 km. What is the minimum distance between two red cars in order for you to be able to clearly distinguish them?
15. The following problems shall demonstrate that our eyes are optimised for the physical limits of resolving power.
    a) The pupil of the human eye has a typical diameter of 3 mm (in normal daylight). Calculate the angular resolution for visible light (e.g. λ = 600 nm).
    b) The photoreceptors in the retina have a mutual distance of 1.5 μm. They are some 20 mm behind the pupil. Calculate their angular resolution and compare the result to the one in a).

Numerical Solutions: 1. wavelength 12 cm, yes; 2. 3.9 cm; 3. 6.4 kV/m; 4. c/8.9, c/1.33; 5. 440 nm; 6. 1.0 kV/m, 3.3 μT; 7. 750 V/m, 1.5 kW/m²; 8. 8.4 GHz; 9. 14 cm/28 cm/42 cm; 10. 1.3 cm; 11. 120 μm; 12. 11 m; 14. about 1 m; 15. 0.24 mrad, 0.15 mrad

Solutions Supplementary Problems
Electromagnetic Waves and Interference

13. a)



b) $f = \dfrac{c}{\lambda} = \dfrac{c}{4/5\,L} = \dfrac{3.0 \cdot 10^8\,\text{m/s}}{0.8 \cdot 0.5\,\text{m}} = 750\,\text{MHz}$

14. The distance between two cars must be such that the distance between the two zeroth diffraction maxima is greater than the distance to the first minimum.

$$\sin\alpha_1 = z_1\,\frac{\lambda}{d} \approx a_1/L \quad \rightarrow \quad a_1 \approx \frac{z_1\,\lambda\,L}{d} = \frac{1.22 \cdot 600 \cdot 10^{-9}\,\text{m} \cdot 3.5 \cdot 10^3\,\text{km}}{3 \cdot 10^{-3}\,\text{m}} = 85\,\text{cm}$$

15. a) $\alpha_1 = \arcsin\left(z_1\,\lambda/d\right) = \arcsin\left(1.22 \cdot 600 \cdot 10^{-9}\,\text{m}/(3 \cdot 10^{-3}\,\text{m})\right) = 0.24\,\text{mrad}$

b) In order to distinguish two points on the retina, there has to be at least one "dark" photoreceptor between two bright ones.

$\alpha_{\text{min}} = \arctan\left(2\,a/L\right) = \arctan\left(2 \cdot 1.5 \cdot 10^{-6}\,\text{m}/0.02\,\text{m}\right) = 0.15\,\text{mrad}$