Waves and optics, solutions

Common themes
Theme 1: Polarizers
Theme 2: Diffraction and interference
Theme 3: Mirrors and thin lenses

Problem 1:
(D) Optical instruments
Keplerian telescope: separation: $f_1 + f_2$, magnification: f_1/f_2. (theme 3)

Problem 2:
(B) Polarizers
transmitted intensity/incident intensity = $0.5*\cos^2(\theta)*\cos^2(90^o - \theta)$.
Maximum at $\theta = 45^o$. (theme 1)

Problem 3:
(B) Interference patterns
Holograms record an interference pattern. A reference beam interferes with a beam transmitted through or reflected by the object. Interference patterns contain amplitude and phase information. (theme 2)

Problem 4:
(E) Thin film-interference
When a light wave reflects from a medium with a larger index of refraction, then the phase shift of the reflected wave with respect to the incident wave is π (180^o). When a light wave reflects from a medium with a smaller index of refraction, then the phase shift of the reflected wave with respect to the incident wave is zero. (theme 2)

Problem 5:
(A) Diffraction limited optics
Light rays from a distant source arrive nearly parallel. Neglecting diffraction, the image of a point will be a disk of approximate diameter d. We want the diameter of the Airy disk (bright center of the diffraction pattern) to be approximately d. The first minimum of the diffraction pattern occurs at approximately $d\sin\theta = \lambda$. We then have $\sin\theta \sim d/D$. Therefore $d \sim (\lambda D)^{1/2}$. (theme 1)

Problem 6:
(E) Phase and group velocity
phase velocity: ω/k, group velocity: $d\omega/dk$.
Information (energy) moves with a speed equal to the group velocity.

Problem 7:
(E) Polarization
For plane polarization the y- and z-components must be in phase or 180^o out of phase. (theme 1)

Problem 8:
(D) Diffraction and interference patterns
Single slit minimum falls on double slit maximum.
Single slit minimum: $w\sin\theta = m\lambda$.
Double slit maxima: $d\sin\theta = n\lambda$.
$w/d = m/n$, $md = nw$. Since $d > w$, the only possible answer is D. (theme 2)

Problem 9:
(C) Mirrors and thin lenses
mirror equation: $1/x_o + 1/x_i = 1/f$, negative image distance → virtual image. (theme 3)

Problem 10:
(E) Diffraction and interference patterns (theme 2)

Problem 11:
(B) Diffraction and interference patterns
Double slit interference: $d\sin\theta = \lambda$, $d = 0.01/2000$ m.
Small angles: $\theta \sim \lambda/d = 0.1$ rad. 2π rad = 360 deg, 1 rad ~ 60 deg, 0.1 rad ~ 6 deg. (theme 2)

Problem 12:
(D) The speed of light in a dielectric
$c^2 = 1/(\varepsilon_0\mu_0)$, $v^2 = 1/(\varepsilon\mu)$, $v^2 = c^2/(\kappa_e\kappa_m)$

Problem 13:
(E) Traveling waves:
$y = A\sin(\omega t - kx)$ represents a wave traveling into the positive x-direction with speed
$v = \omega/k = \lambda/T$

Problem 14:
(A) Thin film-interference
The reflections from the front and rear surface of the layer both produce a phase shift of π. Traversing the layer twice (back and forth) also must introduce a phase shift of π. The waves reflected from the front and back surface of the layer must be out of phase by ½ wavelength to destructively interfere. (theme 2)

Problem 15:
(C) Total internal reflection
$\sin\theta_c = n_{small}/n_{big} = 1/1.33 = ¾$, $\theta_c \sim 50^o$.