Dr. Mohammad Aslam, Dept. Of physics, B.Sc. part-2 physics (Hons) paper-iii lecture no-73

Topic: Half wave and Quater wave Plates

The interaction of light with the atoms or molecules of a material is wavelength dependent. A consequence of this dependence is the resonant interactions related to material **dispersion**. Another consequence of such **resonant interaction** is **birefringence**, the change in refractive index with the polarization of light. The orderly arrangement of atoms in some crystals results in different resonant frequencies for different orientations of the electric vector relative to the crystalline axes. This, in turn, results in different refractive indices for different polarizations. Unlike dispersion, birefringence is easy to avoid: use amorphous materials such as glass, or crystals that have simple symmetries, such as NaCl or GaAs. On the other hand we can "use" birefringence to modify the polarization state of light, a useful thing to do in many situations. The optical components that do this trick are called birefringent wave plate or retardation plate.

Half-wave Plates

By far the most commonly used wave plates are the half-wave plate (G = p) and the quarter-wave plate (G = p/2). The half-wave plate can be used to rotate the plane of plane polarized light as shown in Figure '

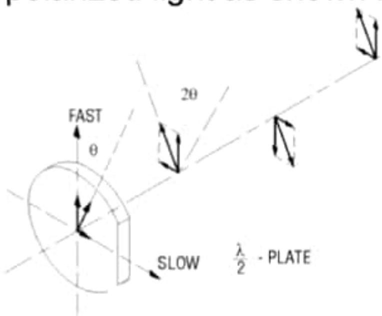

Fig.

Suppose a plane-polarized wave is normally incident on a wave plate, and the plane of polarization is at an angle q with respect to the fast axis. To see what happens, resolve the incident field into components polarized along the fast and slow axes, as shown. After passing through the plate, pick a point in the wave where the fast component passes through a maximum. Since the slow component is retarded by one half-wave, it will also be a maximum, but 180° out of phase, or pointing along the negative slow axis. If we follow the wave further, we see that the slow component remains exactly 180° out of phase with the original slow component, relative to the fast component. This describes a plane-polarized wave, but making an angle q on the opposite side of the fast axis. Our original plane wave has been rotated through an angle 2q. You can satisfy yourself that you will find the same result if the incident wave makes an angle q with respect to the slow axis.

A half-wave plate is very handy in rotating the plane of polarization from a polarized laser to any other desired plane (especially if the laser is too large to rotate). Most large ion lasers are vertically polarized, for example, so to obtain horizontal polarization, simply place a half-wave plate in the beam with its fast (or slow) axis 45° to the vertical. If it happens that your half-wave plate does not have marked axes (or if the markings are obscured by the mount), put a polarizer in the beam first and orient it for extinction (horizontally polarized), then interpose the half-wave plate normal to the beam and rotate it around the beam axis so that the beam remains extinct, you have found one of the axes. Then rotate the half-wave plate exactly 45° around the beam axis (in either direction) from this position, and you will have rotated the polarization of the beam by 90°. You may check this by rotating the polarizer 90° to see that extinction occurs again. If you need some other angle, instead of 90° polarization rotation, simply rotate the wave plate by half the angle you desire.

Incidentally, if the polarizer doesn't give you as good an extinction as you had before you inserted the wave plate, it likely means your wave-plate isn't exactly a half-wave plate at your operating wavelength. You can correct for small errors in retardation by rotating the wave plate a small amount around its fast or slow axes. Rotation around the fast axis decreases the retardation while rotation around the slow axis increases the retardation. Try it both ways and use your polarizer to check for improvement in extinction ratio.

Quarter-wave Plates

Quarter-wave plates are used to turn plane-polarized light into circularly-polarized light and vice versa. To do this, we must orient the wave plate so that equal amounts of fast and slow waves are excited. We may do this by orienting an incident plane-polarized wave at 45° to the fast (or slow) axis, as shown in Figure

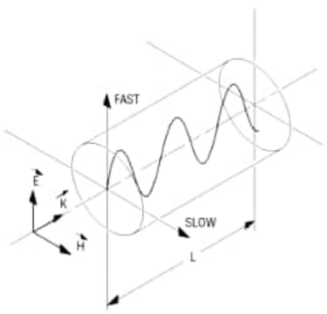

Fig.

On the other side of the plate, we again examine the wave at a point where the fast-polarized component is maximum. At this point, the slow-polarized component will be passing through zero, since it has been retarded by a quarter-wave or 90° in phase. If we move an eighth wavelength farther, we will note that the two are the same magnitude, but the fast component is decreasing and the slow component is increasing. Moving another eighth wave, we find the slow component is maximum and the fast component is zero. If we trace the tip of the total electric vector, we find it traces out a **helix**, with a period of just one wavelength. This describes **circularly polarized light**. Right-hand light is shown in the Figure; the helix wraps in the opposite sense for left-hand polarized light. You may produce left-hand polarized light by rotating either the wave plate or the plane of polarization of the incident light 90° in the Figure.

Setting up a wave plate to produce circularly polarized light proceeds exactly as we described for rotating 90° with a half-wave plate: first, cross a polarizer in the beam to find the plane of polarization. Next, insert the quarter-wave plate between the source and the polarizer and rotate the wave plate around the beam axis to find the orientation that **retains**the extinction. Then rotate the wave-plate 45° from this position. You should now have half the incident light passing through the polarizer (the other half being absorbed or deflected, depending on which kind of polarizer you are using). You can check the quality of the circularly polarized light by rotating the polarizer -- the intensity of light passing through the polarizer should remain unchanged. If it varies somewhat, it means the light is actually **elliptically polarized**, and your wave plate isn't exactly a quarter-wave plate at your operating wavelength. You may correct this as with the half-wave plate by tilting the wave-plate about its fast or slow axes slightly, while rotating the polarizer to check for constancy.

You may wonder what effect retardations other than a half-wave or a quarter-wave have on linearly polarized light. Figure 5 shows the effect of retardation on plane polarized light with the plane of polarization making an arbitrary angle with respect to the fast axis.

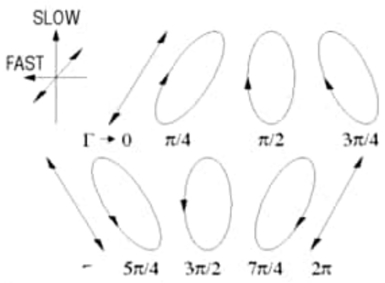

Fig. ’

The result is elliptically polarized light, with the amount of ellipticity and the tilt of the axis of the ellipse a function of the retardation and the tilt of the incident plane wave. The exception is a half-wave retardation, in which case the ellipse degenerates into a plane wave making an angle of 2q with the fast axis. Note that the quarter-wave plate does not produce circularly polarized light here, because equal amounts of fast and slow wave components were not used; the incident tilt angle must be exactly 45° with respect to the fast (or slow) axis to make these components equal.

Wave Plate Applications

We have already mentioned the two most common applications of wave plates: rotating the plane of polarization with a half-wave plate and creating circular polarization with a quarter-wave plate. Obviously, you can also use a quarter-wave plate to create plane polarization from circular polar-ization -- just reverse the direction of light