Learning Wave Optics through the Computer Simulation

Donggyu Yim, Sungmuk Lee
Department of Physics Education

Wave optics, one of the important physics conception, is selected as the contents of a physics subject in this paper. This 'computer based learning method' can be used as one of the many methods for the undergraduates to correct misconception. Students can not easily correct the misconception through the traditional insturction method. This 'computer based learning method' can be one of strategies for correcting the misconception.
In this study, 'computer based learning method' is essentially composed of 'instruction about the computer' and 'instruction through the computer'.
This can help students to correct the misconception. And students can acquire the ability to study the complicated physics concept by using computer, as physicists do.

I. Introduction

Physics should be learned very importantly because it is one of the essential parts of natural science and it also influences on modern industries greatly.

However, according to Peter's study, when the students learn physics by the traditional method, even honors students would have the misconception as general undergraduates did. This is an example that even honors students of university have difficulty in studying physics concept correctly.[1]

When physics education is performed in the traditional method in Korea, undergraduates have a small chance to correct the misconception, too. Kwon (1993) had quoted a instruction strategy to correct the misconception such as 'learning cycle', 'conceptual change model', 'teaching model by reflective thinking' and 'teaching with analogy models'.[2]

This paper propose that 'computer based learning strategy' helps students to correct the misconception of physics

According to Wilson, computer based learning method is good to decrease the gap of difference between the contents of physics taught in school and the contents that physicists have.[3] Computer based learning method can help students to experience the enterprise of modern physics better than by usual analytic method and it also help students to approach easily broader phenomena. Also it can help students to study the contents of the complicated physics in an easier way.[3]

These days physicists use computer to solve the problems in most activities. If computer based learning method is introduced into the undergraduate instruction, students can acquire the ability to study complicated physics concepts by computer. Owing to this, computer based learning method may be effective than the traditional method.

Wave optics, one of the important physics conceptions, is introduced as a physics subject in this paper. This example is shown here as a basic strategy by using computer simulation to correct the misconception, when junior and senior students learn wave optics.

The content of wave optics, which had learned before junior and senior years in the university, is as follows.

II. Learning Wave Optics in Curriculum

For the first time, students have access to learning for 'light' when they are in the second grade of elementary school. The fourth grade students of elementary school learn the content a little, and high school students learn it, too. There is no section for 'light' instruction in middle school curriculum.

In learning for light conception, especially in wave optics, the concepts of 'diffraction' and 'interference' are an important part of wave phenomena. These two contents of 'interference' and 'diffraction' are also the fundamental steps for learning modern physics. We consider only the contents of diffraction in this paper. Now the contents of 'diffraction' for students to learn before junior and senior years in the university will be introduced here.

A. Optics learning in Elementary and Middle School

In elementary and middle school, the contents of wave optics are not taught, but the contents of 'optics' will be introduced briefly here.

The second grade elementary students learn the 'light' in the 'light and shadow' section of the textbook. This section is divided into four subsections; 'brightness and darkness', 'shadow game', 'shape of object and shadow', and 'change of shadow'. Through this section students learn the relation of the light and shadow by studying the reason of shadow forming and the conditions which change the shape of shadow.

The fourth grade students learn the geometric characters of light; the rectilinear propagation of light, the reflection and the refraction of light, etc. In the rectilinear propagation they learn the behavior of light propagation in the water and air, the relation of object position and the size of shadow, and the image of pinhole camera. In the reflection of light they learn the law of reflection and the image by the mirror. In the refraction of light they learn the refraction by the water and by the lens, and the dispersion by the prism.

In the curriculum of middle school there is no formal section which deals with 'optics', but there are some comments about light relating to solar energy and astronomic telescope.

B. 'Diffraction' learning in high school

High school students learn the diffraction of light in two subsections of 'light and waves' section; 'the interference and diffraction of waves' and 'the wave property of light'. In the curriculum of high school the diffraction of light is treated in order to prove the wave property of light by the diffraction of waves and there is not much difference between contents for the scientific oriented students course and those for liberal arts oriented students.In most textbooks, diffraction is explained in a qualitative way for the wave phenomena, showing the diffraction of water wave passing through the small gap as an example, but in some textbooks the principle of Huygens is also introduced. The diffraction of light is treated upto the level of presenting double slit, single slit, and the diffraction phenomena in the circular hole. For double slit the examples of equations for calculating the position of fringe on the screen and treating approximation, are presented.

In high school, the objectives of the learning 'diffraction of light' are not only learning subject itself but also understanding wave property of light through the learning of diffraction and having the foundation of understanding the duality of light in modern physics.

C. 'Diffraction' learning in the university

In the university, wave optics is treated in the several sections on the freshman physics course. Though there are some differences among books, the related sections are generally grouped by 'INTERFERENCE' and 'DIFFRACTION'. In the interference section many interference fomula, having advantage to have close relationship with everyday phenomena are first presented. Secondly, students study again the basic concepts of diffraction learned in high school, and then they deepen the knowledge in 'diffraction' section. In diffraction section, students quantitatively treat the single slit diffraction phenomena with numerical analysis, and learn the vector addition method through phasor diagram. Diffraction of circular aperture is also treated to deal the topic of resolution. After this, students learn the diffraction in double and multiple slit.

Through this instruction, students learn the intensity distribution at the shadow behind the obstacle not by using the 'particle model' of Isac Newton, but the 'wave effect' being calculated by Fresnel.

III. Computer based learning method

The Instruction flow charts in Fig. 1 shows the outline of the 'traditional instruction method' and the 'Computer based learning method'.

A. Computer based learning method for correcting misconception

In this paper, 'diffraction' of wave optics in physics is mainly dealt.

In high school, students used to learn diffraction in 'light and waves' section through the traditional instruction method. After

INSTRUCTION FLOW CHART

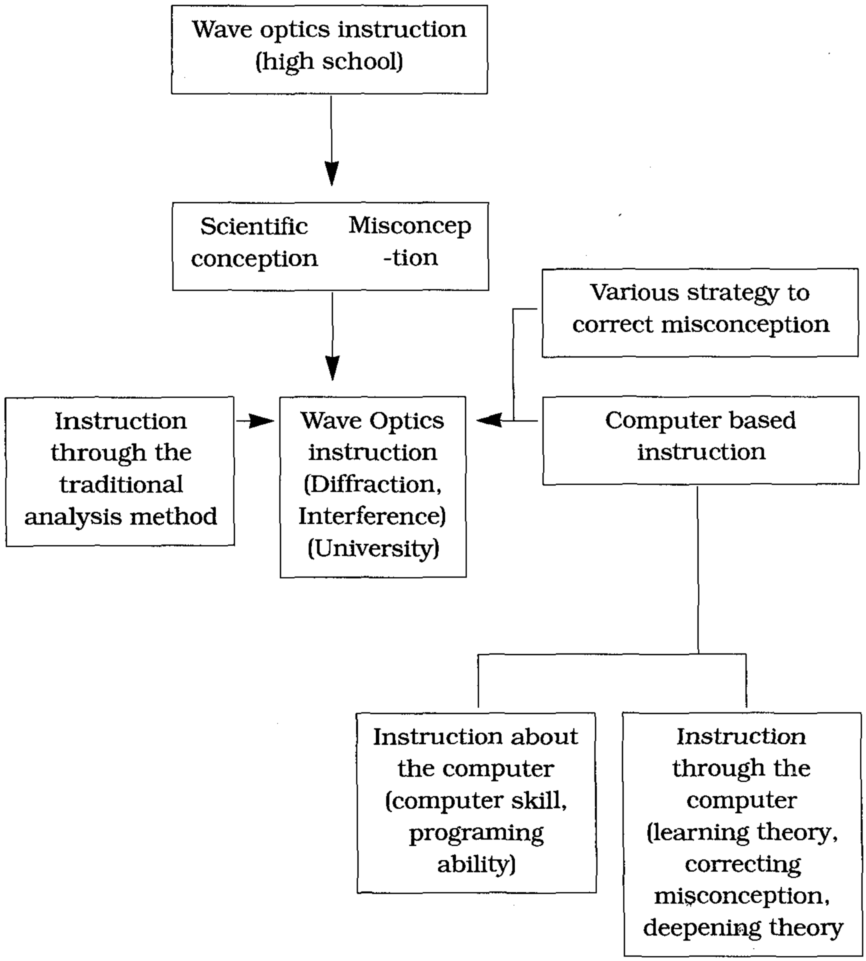

Fig. 1.

that, students learn again 'wave optics' in undergraduate course, then students can easily hold the following misconception about 'light'.

Many students can not understand that 'light' is the physical substance propagating the space, and they have the misconception about 'light propagation' that 'light' propagates to any particular direction rather than to all directions.[4][5][6][7] Moreover students think that 'light' is cut off from 'seeing' (:

Decoupling Concept).[6] This concept affects the perception character of natural phenomena. There is no doubt that students who have such a misconception in the natural phenomena, will have the misconception in 'wave optics' part, too.

For the undergraduates in the university education, we instruct 'Fresnel diffraction' with 'Fundamentals of Optics' textbook[8] (as a textbook in our Department of Physics Education). 'Fresnel diffraction' has been taught by the traditional instruction method which uses a lot of tabled materials. We see that many students have difficulty in understanding the complicated integral equation[8] and have the abstract preconception about Fresnel diffraction.

If we only use the traditional instruction method, students can not easily correct the misconception, too. To correct the misconception, various strategies (Learning cycle, Conceptual change model, teaching model by reflective thinking, Teaching with analogy models) are quoted by Kwon. We think that this 'Computer based learning method' can be one strategy for correcting the misconception. In this study, 'Computer based learning method' is essentially composed of 'instruction about the computer' and 'instruction through the computer'. In 'instruction about the computer', students should learn computer composition, computer skill, and acquire computer programing ability, by themselves. In 'instruction through the computer simulation', students can investigate the changing process with controling various physical variables, and under the various simulation conditions students can compare the various diffraction patterns by themselves. Through this process, students can correct the misconception and learn Fresnel diffraction effectivly.

B. Computer based learning strategy

The concrete instruction process is, as follows.

Through the programming process in groups, students will learn how to communicate ideas among themselves, how to formulate arguments and logical paths of thought using computer language.

After this process, they can obtain the simulation program.

By the Fresnel diffraction simulation program, they can see

Fresnel diffraction pattern through the computer monitor screen, which can not be easily seen by experiments.

For example, the intensity distribution just behind the knife edge obstacle which we see in everyday life is step shape as Fig. 2-1. When the distance between knife edge and screen is gradually increased, even the best university students can not easily explain the intensity distribution and can not easily obtain the exact solution by the numerical analysis.

If we instruct students through the computer based simulation, students can easily see the changing Fresnel diffraction pattern (as Fig. 2-2, 2-3) through the simulation. And they can compare the diffraction patterns at textbook with the simulation results, as various variables change.

Now the students can learn Fresnel diffraction with the sense of sight through the simulation. This can help students to correct the misconception, too.

And students can acquire the ability to study the complicated physics concept by using computer, as physicists do. Owing to this merits, computer based learning method can be much more effective than the traditional method in the teaching of wave

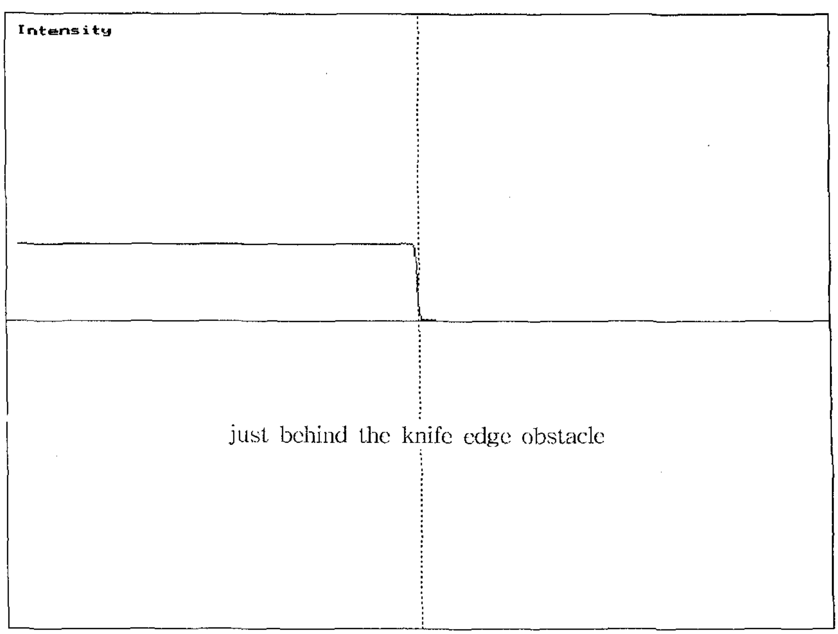

FIG. 2-1
SHADOW JUST BEHIND KNIFE EDGE

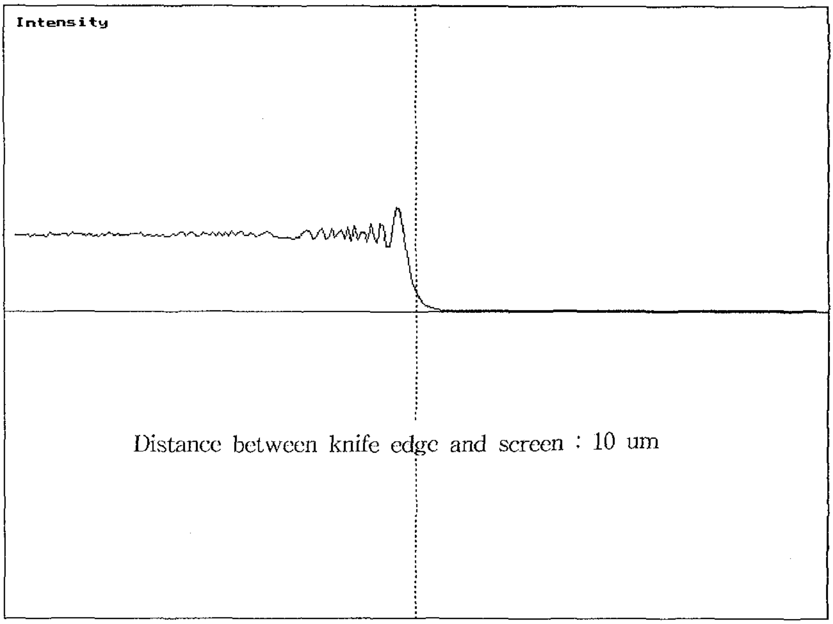

FIG. 2-2
SHADOW BEHIND KNIFE EDGE 10μm AWAY

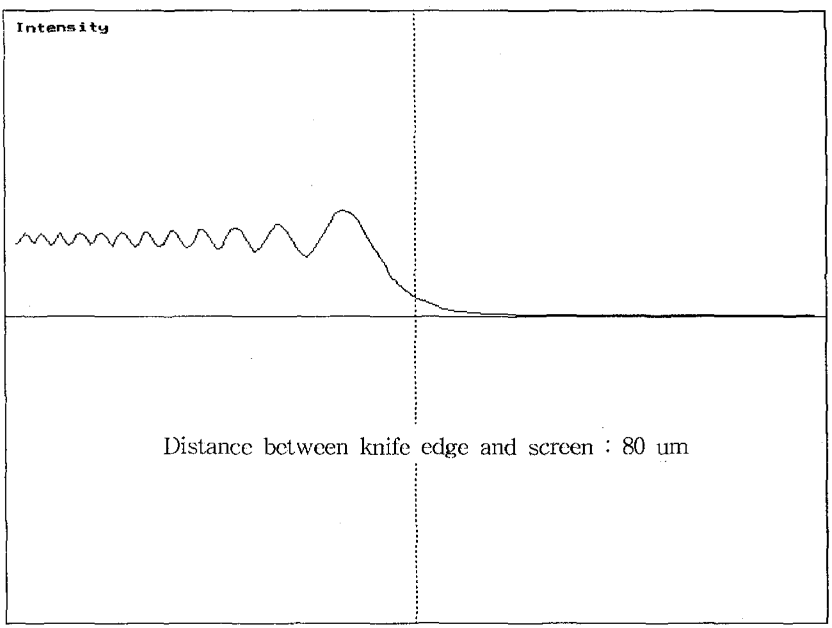

FIG. 2-3
SHADOW BEHIND KNIFE EDGE 80μm AWAY

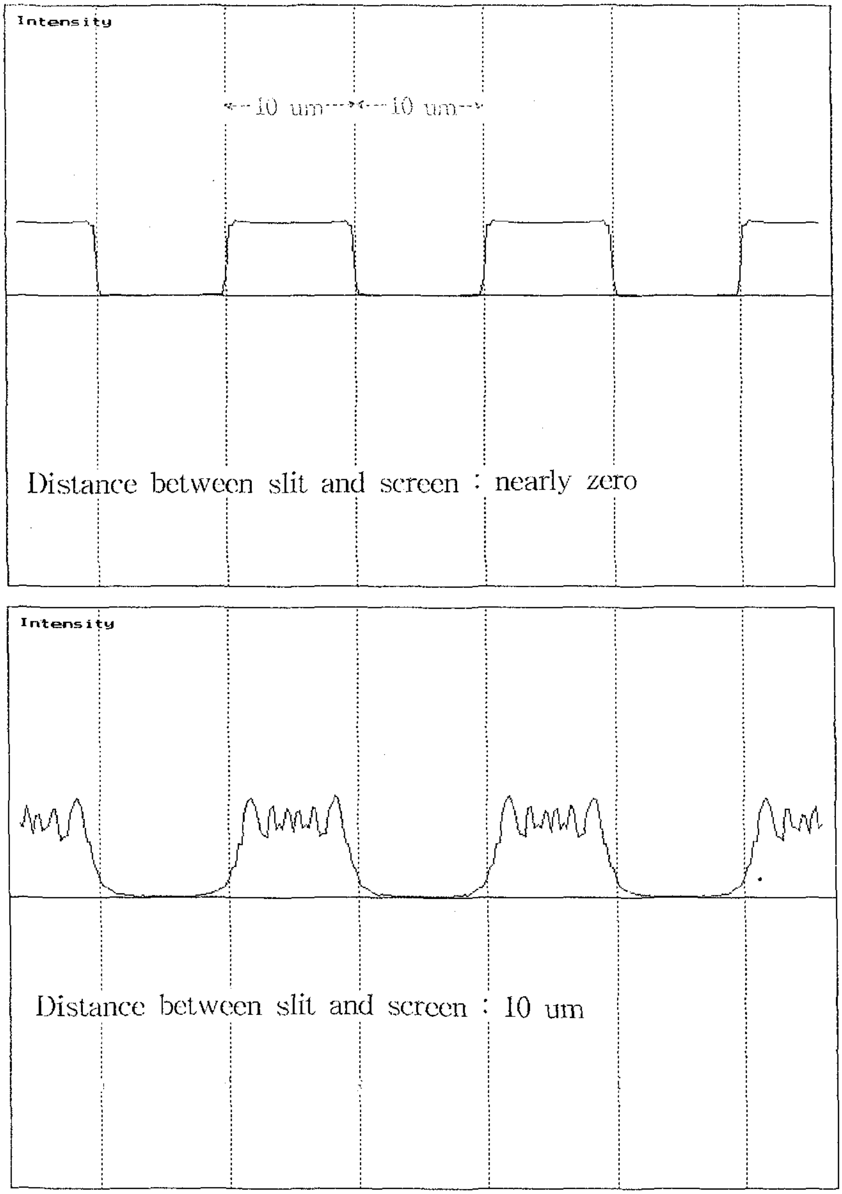

FIG. 3
DIFFRACTION PATTERN BEHIND SCREENED WINDOW 10μm AWAY (SLIT/SPACE = 10/10 μm)

optics.

IV. Result of Simulation

The basic equation and simulation program are in the Appendix. The variables of simulation are the wavelength of light source, slit number (single slit, double slit, multiple slit), slit and space width, the distance between slit and screen.

The following shows some examples of simulation output which you can easily apply to explain yourself diffraction observations in everyday life.

Example 1: Diffraction behind slits such as screened window.

Fig. 3 shows a plot of the change of Fresnel diffraction pattern at a wavelength of 0.5 μm, for slit/space width = 10/10 μm (multiple slit), and the distance between slit and screen are nearly zero and 10 μm respectively.

Example 2: Diffraction behind single obstacle such as hair.

Fig. 4 shows a plot of the change of Fresnel diffraction as the distance between obstacle and screen increases, at a wavelength

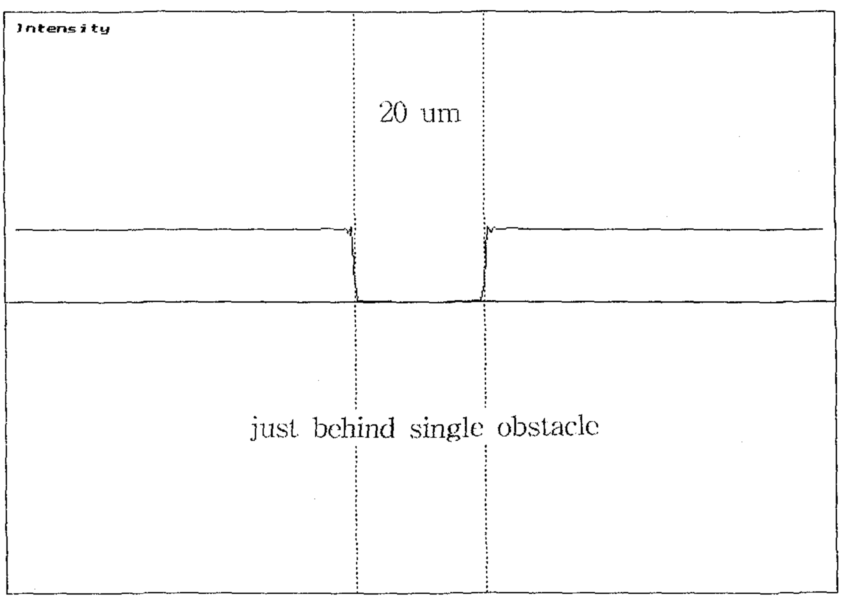

FIG. 4-1

DIFFRACTION PATTERN JUST BEHIND SINGLE OBSTACLE (WIDTH = 10 μm)

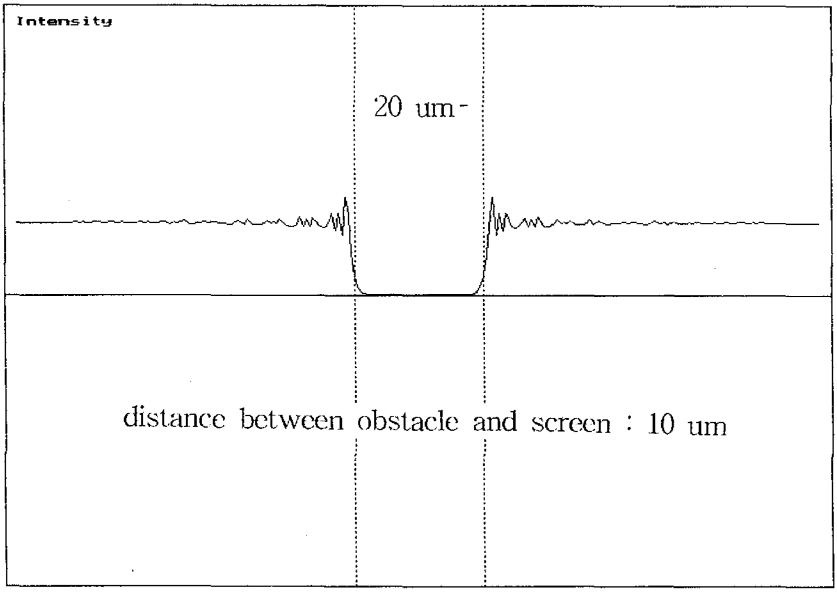

FIG. 4-2
DIFFRACTION PATTERN BEHIND SINGLE OBSTACLE 5 μm AWAY (WIDTH = 10μm)

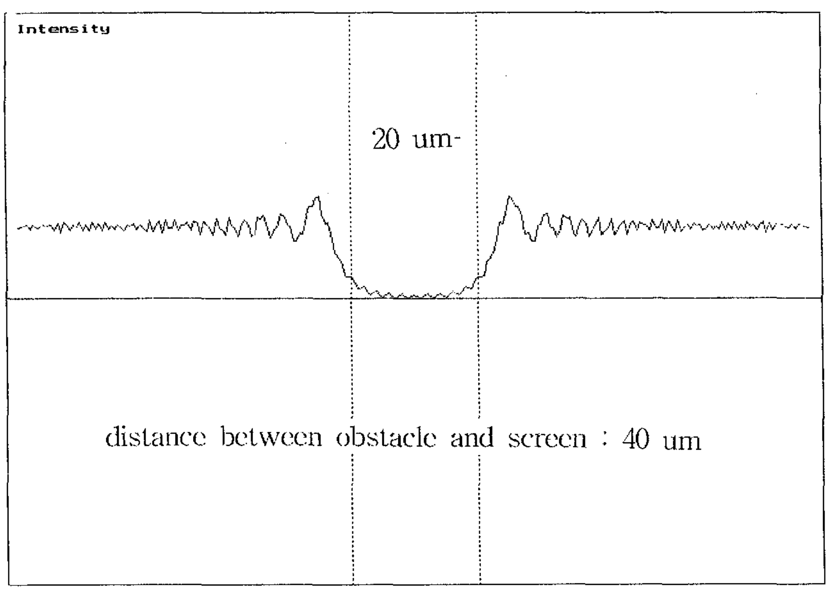

FIG. 4-3
DIFFRACTION PATTERN BEHIND SINGLE OBSTACLE 50 μm AWAY (WIDTH = 10 μm)

of 0.5 μm, for single obstacle. At just behind single obstacle, the intensity distribution is like Fig. 4-1. When the distance between obstacle and screen is gradually increased, the diffraction pattern changes as Fig. 4-2, 4-3.

Because the students can study with the sense of sight through the simulation, computer based learning method may be prior to the traditional method. And students can acquire ability to study the complicated physics concept by computer, as physicists do. These simulations can easily explain everyday diffraction phenomena such as light pattern after the screened window, your eyebrows, and water 'particles' in the air (halo). Therefore students can learn physics with fun, too.

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Appendix

–Fresnel Diffraction Theory–

See F.A. Jenkins & H.E. White, 'Fundamentals of Optics', pp. 378-402.

–Simulation program is, as follows.

```
  /* Fresnel diffraction */

#include<stdio.h>
#include<stdlib.h>
#include<math.h>
#include<graphics.h>

void main (void)
{
  FILE *fp;
  struct {
  double v,x,y;
  } data[800];
  double x1,y1,x2,y2,x,y,PR;
  double d1=10,d2=10,S,b=100,lamda=0.5,l0=0,I0=0,D0=0,l,I,D,
time=0.5;
  char c;
  int N=2,n,v1,v2;
  int gd=DETECT,gm,cx,cy;

  /* read data */
  fp=fopen ("fre.dat","rb");
  fread (data,sizeof(data),1,fp);
  fclose (fp);
```

```
/* input variables */
clrscr ();
printf ("slit number = "); scanf (" %d",&N);
printf ("slit width (um) = "); scanf (" %lf",&d1);
printf ("slit space (um) = "); scanf (" %lf",&d2);
printf ("wavelength (um) = "); scanf ("%lf",&lamda);
printf ("distance between Slit and Screen (um) = "); scanf("%lf",
&b);

initgraph (&gd,&gm,"");
cx=getmaxx()/2;
cy=getmaxy()/2;

do{

  rectangle (0,0,getmaxx(),getmaxy());
  line (0,cy,getmaxx(),cy);
  outtextxy (10,10,"Intensity");

  S=(N*d1+(N-1)*d2)/2;

  setlinestyle (DOTTED_LINE,0,NORM_WIDTH);
  line (0,cy,getmaxx(),cy);
  for (n=1;n<=N;n++){
    if (cx+(-S+(n-1)*(d1+d2))*10>=0 && cx+(-S+(n-1)*(d1+d2))
    *10<=getmaxx())
      line (cx+(-S+(n-1)*(d1+d2))*10,0,cx+(-S+(n-1)*(d1+d2))
      *10,getmaxy());
    if (cx+(-S+(n-1)*(d1+d2)+d1)*10>=0 && cx+(-S+(n-1)*
    (d1+d2)+d1)*10<=getmaxx())
      line (cx+(-S+(n-1)*(d1+d2)+d1)*10,0,cx+(-S+(n-1)*(d1+d2)
      +d1)*10,getmaxy());
  }
  setlinestyle (0,0,1);

  for (l=-cx/10;l<=cx/10;l+=.25) {
    x=0;
    y=0;
    for (n=1;n<=N;n++){
```

```
v1=(int)(20*(-S+(n-1)*(d1+d2)-l)*sqrt(2/(b*lamda)));
if(v1>=0){
  if(abs(v1)<800){
    x1=data[v1].x;
    y1=data[v1].y;
  }
  else {
    x1=0.5;
    y1=0.5;
  }
}
else {
  if (abs(v1)<800){
    x1=-data[-v1].x;
    y1=-data[-v1].y;
  }
  else {
    x1=-0.5;
    y1=-0.5;
  }
}

v2=(int)(20*(-S+(n-1)*(d1+d2)+d1-l)*sqrt(2/(b*lamda)));
if (v2>=0){
  if(abs(v2)<800){
    x2=data[v2].x;
    y2=data[v2].y;
  }
  else {
    x2=0.5;
    y2=0.5;
  }
}
else {
  if (abs(v2)<800){
    x2=-data[-v2].x;
    y2=-data[-v2].y;
  }
  else {
    x2=-0.5;
```

```
            y2=-0.5;
          }
        }

      x+=x2-x1;
      y+=y2-y1;

      }

      I=x*x+y*y;

      if(l!=-cx/10){
        line(cx+10*l0,cy-I0*30,cx+10*l,cy-I*30);
      }

      l0=l;
      I0=I;

    }

    switch (c=getch()){
      case '8':b*=2;break;
      case '2':b/=2;break;
      default:break;
    }
    clearviewport();

  } while(c!=0x1b);

  closegraph();

)
```