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Javaoptics simulations: Open-source physics (OSP) library for teaching (or Learning) thin-film optics

Hayfa G.Rahid¹, Alaa N.Abd Al-Gaffar², Nadir F.Habubi^{1*} ¹Al-Mustansiriyah University, College of Education, (IRAQ) ²Baghdad University, College of Science for Women, (IRAQ) E-mail: nadirfadhil@yahoo.com

ABSTRACT

To illustrate and broaden knowledge on some aspects of physics at teaching level, that is, university level and higher level, Javaoptics applets was adopted as free software under a GNU General Public License, an open-source license. This applet was used to shows multiple beam interferences from a parallel dielectric thin film and to study the evolution of reflection (or transmission)at normal and oblique incidence of light. Further, the reflection and refraction factors when the index of refraction (may be constant or have a wavelength dependency) and the absorption of the film and the substrate are modified. It was shown that resources can be used as an ordinary course to support material and as the main working tool in an on-line Internet course. © 2012 Trade Science Inc. - INDIA

INTRODUCTION

Java is a high-level, third generation programming language (from SUN Microsystem), like C, Fortran, smalltalk^[1-7]. It was used to write computer applications that crunch numbers, process words, play games, store data or do any of thousands of other things computer software. Among the different types of programs^{[3-} ^{8]} that can be written in Java or other language, are primarily interested is applets. These applets introduced in the first version of the Java language in 1995, which required a WWW browser or another Java application to run, so it is an excellent teaching (or learning) language. In the hope of helping in teaching thin-film optics course, we adopt Javaoptics simulations (JOPTICS), as a part of of physics disciplines (physical optics). Javaoptics^[4] is an open source software under GNU General Public (GPL)License^[9], freely available on the web site, http://www.ub.es/javaoptics/applets/ index app.html"^[4]. We believe that the availability of such open-source software is significant advance for the optical coating community.

THEORITICAL BASIS

Multiple beam interference

A plane wave incident from the medium (refractive index 1) onto a thin-film layer with an angle ε and with amplitude E_0 , shown in Figure 1. The amplitude of the transmitted wave into the film can be expressed as $E_0 t_1$, where t₁ can be the Fresnel coefficient for each of the two possible polarizations 's' or 'p'. This plane wave propagates inside the thin-film with an angle ɛ' and undergoes multiple reflections. The amplitude after the first reflection on the film-substrate interface is $E_0 t_1 r_2$ where \mathbf{r}_2 is the Fresnel reflection coefficient from the film to the substrate. At this point, part of the wave is also

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transmitted with amplitude $E_0t_1t_2$ where t_2 is the Fresnel transmission coefficient from the film to the substrate. After the second reflection inside the film, the amplitude of the reflected wave is $E_0t_1r_2r_1$ where r_1 is the Fresnel reflection coefficient from the film to the incident medium. This wave is then transmitted to the substrate with amplitude $E_0t_1r_2r_1t_2$. Thus, the amplitude of the m-th transmitted wave onto the substrate is^[10,11]:

$$E_{m} = E_{0} t_{1} t_{2} \left(r_{1} r_{2} \right)^{m}$$
 (1)



Figure 1 : Sketch of the multiple reflections inside a thinfilm layer^[10].

To analysis the relative phase of each of the transmitted waves, it is necessary to take two reference points in two consecutive transmitted waves and the these two points are placed on the same plane perpendicular to the propagation direction of the waves, as indicated in Figure 2.



Figure 2 : Optical path difference between two consecutive transmitted waves.

The optical path difference between two consecutive transmitted waves is:

$$\Delta = n(AB + BC) - n'AD = 2nd\cos\varepsilon'$$
(2)

The phase corresponding to this optical path is:

$$\delta = \frac{2\pi}{\lambda} 2 \text{nd}\cos\varepsilon' \tag{3}$$

Thus, the complex amplitude of the m-th transmitted wave can be expressed as:

$$E_{m} = E_{0}t_{1}t_{2}(r_{1}r_{2})^{m} \exp\left(i\cdot m\left[\phi + \arg\left(r_{1}\right) + q\right]\right) = E_{0}t_{1}t_{2}(r_{1}r_{2})^{m} \exp\left(i\cdot m\left[\phi + \delta\right]\right)$$
(4)

The modulus and phase of the Fresnel reflection coefficients r_1 i r_2 have been written separately. The phases $arg(r_1)$ and $arg(r_2)$ can be different from 0 in those cases when the refractive index of the substrate is greater than the refractive index of the film $(arg(r_2)=\pi)$ or when the extinction coefficient of the film is not zero ($k\neq 0$, $arg(r_1)\neq 0$ and $arg(r_2)\neq 0$).

The total resulting amplitude is the sum of the complex amplitudes of all the transmitted waves:

$$E = \sum_{m=0}^{\infty} E_0 t_1 t_2 (r_1 r_2)^m \exp(i \cdot m[\varphi + \delta]) =$$

$$E_0 t_1 t_2 \frac{1}{1 - r_1 r_2 \exp(i[\varphi + \delta])}$$
(5)

The resulting transmitted intensity is proportional to the square modulus of the total transmitted complex amplitude, i.e.:

$$I = \frac{|E_0 t_1 t_2|^2}{1 + (r_1 r_2)^2 - 2r_1 r_2 \cos(\varphi + \delta)} = \frac{|E_0 t_1 t_2|^2}{(1 + r_1 r_2)^2 - 4r_1 r_2 \cos^2([\varphi + \delta]/2)}$$
(6)

where the relation $\cos(\varphi)=2\cos^2(\varphi/2)-1$ has been applied. Analyzing the previous expression, the conditions a maximum or minimum of transmitted light can be deduced. For instance, for a dielectric film (with k=0) these conditions can be summarized on the following table:

(m=0,1,2,)	n <n'< th=""><th>n>n'</th></n'<>	n>n'	
Maximum transmitted	Indees(e')-m)	$2ndcos(\epsilon')=$	
intensity	$2\Pi u \cos(\varepsilon) - \Pi h$	(2m+1)λ/2	
Minimum transmitted	$2ndcos(\epsilon')=$	$2nd\cos(a^2)-m^2$	
intensity	(2m+1)λ/2	2110008(8)-1111	

Concerning the reflectance, its behavior is the opposite to the transmittance: where the former is maximum the latter is minimum and vice-versa. In the case when the film is slightly absorbing (extinction coefficient different from 0) the conditions for having a maximum or a minimum in the transmittance are more complex since they have to take into account the phase δ . The



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final Reflectance and Transmittance of the sample depend as well on the Reflectance and Transmittance of the second face of the substrate. Since the latter do not depend on the characteristics of the film, this second face does not affect the distribution of R and T maxima and minima.

RESULT AND DISCUSSION

Very short user guide

We first present a very short user guide and the structure of the implementation of Javaoptics. All the functions of Javaoptics are accessible through a graghical user interface (GUI) which is designed so that the vast majority of the information is presented in a single main window, shown in Figure 3.



Figure 3 : Applet shows multiple beam interferences from a parallel thin film^[5].

(a) Window 'Transmission and Reflection'

This window shows a sketch of the sample with the substrate in blue and the film on its top in yellow. Incident light is represented by a set of beams in green while light reflected is represented in a set of magenta beams. Transmitted light is represented in cyan. The sketch of the sample includes also the values of transmittance (T) and reflectance (R) of the sample. It is worth noting that the light is assumed to be monochromatic and with natural polarization (a uniform superposition of all possible polarization states).

The window "Transmission and Reflection" allows changing the thickness of the layer (d), the wavelength of the incident light (λ), and the angle of incidence (θ). Furthermore, the values of the refractive index (n) and extinction coefficient (k) can be changed by means of the buttons "Change n" and "Change k". These buttons open two windows with the names "Refractive index

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parameters" and "Extinction coefficient parameters" respectively. These parameters correspond to a mathematical model for the refractive index and the extinction coefficient that follows the expression:

$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}; \quad k(\lambda) = k_0 \exp(D/\lambda)$$
(7)

These windows allow changing the values of A, B, C, k_0 and D and show a plot of these indexes against the wavelength as shown in Figure (4-7) for normal and oblique incident of light when dielectric and absorbing materials were used.

(b) Window 'Phase Difference'

This window shows a diagram of the path followed by a beam inside the thin film. For the selected wavelength it shows the value of the refractive index and of the extinction coefficient of the film (n and k on the diagram), as well as the refractive index of the substrate. The window allows changing the thickness of the film (d), the wavelength (λ) the angle of incidence (ϵ). In addition, the values of the refractive index and of the extinction coefficient can be changed with the buttons "Change n" and "Change k". Figure 7 and 8 illustrate this windows for normal and oblique incidence.

(c) Window 'Spectrum'

This window shows the Reflectance and Transmittance spectra for the sample with the current configuration. It has to be kept in mind that these values are the result of the transmission and reflection on the film and also on the second face of the substrate. By placing the cursor on the plot, the values corresponding to the position with respect to the coordinate axes on the graph can be read on the lower part of the window. The button "Configure Plot" allows defining the way the plot is presented in Figure 4 and 6. The lower and upper limits of the wavelength represented on the plot can be defined as well as the lower and upper limits of the reflectance and transmittance represented on the plot. These last two values can be assigned automatically with the buttons on the lower part of the window. Thus, the button "R/T Range 0/1" assigns the value 0 to the "Initial T and R value" and 1 to the "Final T and R value". The button "Auto Range" assigns automatically the minimum R/T range that permits representing simultaneously the two spectra. The buttons "Auto

Interferences in This Film Continue	•
r Interrerences in Thin-Film Coatings	
Transmission and Reflection Phase Difference	Spectrum T Maxima and Minima
R(550.0)=0.08	Spectrum Initial Wavelength (400
	Spectrum Final Wavelength (n 800
T(550.0) = 0.921	Initial T and R value 0
	Final T and R value 1
Thickness	R/T Range 0-1 Auto Range
0 3000 0 nm	Auto Range R Auto Range T
Wavelength 400 800 _550 nm	
ungle of incidence 0 0 0	Ok
n -> A=2.71E0 B=2.64E4 C=1.3E8 Change n	
k -> k0=0E0 D=2253 Change k	
Substrate: Glass Substrate: Air	
Experiment	lain About Evit
Experiment	
Interferences in Thin-Film Coatings	
Transmission and Reflection Phase Difference	Spectrum T Maxima and Minima
R(550.0)=0.08	
	0.7
T(550.0) = 0.92	0.6⊢ – ⊢
	a ² 0.5⊢ –
$\downarrow \downarrow \downarrow \downarrow \downarrow \downarrow$	0.3-
Thickness 0 0 nm	
Wavelength 400 800 550 nm	400 440 480 520 560 600 640 680 720 760 80
	Wavelength (nm)
ngle of incidence 0 0 0	R/T: 0.03
n -> A=2.71E0 B=2.64E4 C=1.3E8 Change n	Configure Graph
k > k0=0E0 D=2253	
Change K	
Substrate: Glass O Substrate: Air	

Figure 4 : Main JOPTICS windows showing; (A) The spectrum window, (B) Transmission and reflection window for glass substrate of index $n_g = 1.52$ at $\lambda_0 = 550$ nm.(normal incidence).



.	*	
Refractive index n parameters 💦 📑 🔀	🖆 Interferences in Thin-Film Coatings	
1.39	Transmission and Reflection Phase Difference	Spectrum T Maxima and Minima
1.39 1.39	R(550.0)=0.00	
1.39-		0.9-
1.38		0.7-
1.38-	T(550.0)= 0.92	0.6- ⊢
1.37		α2 ⁻⁰⁻³ 0.4−
1.37		0.3-
1.37 200 260 320 380 440 500 560 620 680 740 800 Wavelength (nm)	Thickness 0 2000 00.637 nm	0.1
a 1	Wavelength 400 800 550 nm	0 440 480 520 580 600 640 880 720 780 80 Wavelength (nm)
0 0 0 0 (nm^2)	Angle of incidence 0	Wavelength: 584.82 nm R/T: 0.03
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	n -> A-1.38E0 B-0E0 C-0E0 Change n	Configure Graph
Ok	k .> k0=0E0 D=0 Change k	
	🕘 Substrate: Glass 🗌 Substrate: Air	
	Experiment Held	About
Extinction coefficient k parameters	Interferences in Thin-Film Coatings	
(the second sec	Transmission and Reflection Phase Difference	Spectrum T Maxima and Minima
0.9	Ⅰ ↓ 作 作 作 ↑ ↑ R(549.3) = 0.05	1
0.7		0.9
		0.8-
		0.6
).3	1(549.9) = 0.95	
	$\downarrow \downarrow \downarrow \downarrow \downarrow \downarrow$	0.4-
10	Thickness 0	0.2
Wavelength (nm)	Wavelength 400 800 550 nm	0 400 440 480 520 580 600 640 680 720 780 8
	Angle of incidence	Wavelength: 790.76 nm
0 V 20 V 6-3	90 p °	RT: 0.3
0 0 0 0 mm	n-> A-1.38E0 B-0E0 C-0E0 Change n	Contigure Graph
	k > k0=0E0 D=0 Change k	
Ok		
Ok	Substrate: Glass	

Figure 5 : Joptics windows showing the T and R spectrum (normal incidence) of MgF₂ on glass of geometrical thickness d=99.637 nm at λ_0 =550nm; (A) The refractive index n window, (B) The extinction coefficient k window.

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Full Paper 📓 Extinction coefficient k parameters 🔳 🗆 🔀 曫 Interferences in Thin-Film Coatings 160.55 Transmission and Reflection Phase Difference Spectrum T Maxima and Minima 144.51 128.47 112.43 96.39 80.35 Ô. 64.31 T(549.9)=0.13 48.28 0. 32.24 16.2 Thickness 5000 150 nm 0 0.1 Wavelength (nm) Wavelength 550 nm 400 900 400 440 480 520 560 600 640 680 720 760 800 Wavelength (nm) Wavelength: 418.48 nm Angle of incidence 🔋 💭 💷 go 20 <u>10.05</u> e-3 k0 g 🚃 R/T: 0.38 Configure Graph D 0 _____ 5000 942.00 nm n > A-2.368E0 B-3.158E4 C-3.948E8 Change n k->k0=1.605E-2 D=1842 Change k 0k 🖲 Substrate: Glass 👘 🔵 Substrate: Air Help About Exit Experiment 😹 Extinction coefficient k parameters 🔳 🗆 🔀 🖶 Interferences in Thin-Film Coatings 160.55 Transmission and Reflection Phase Difference Spectrum T Maxima and Minima 144.51 128.47 112.43 96.39 80.35 64.31 48.28 32.24 16.2 Thi okness 0 Q 3000 150 nm 0 16 200 260 320 380 440 500 560 610 680 740 800 Wavelength (nm) Wavelength 400 - 800 550 nm 400 440 480 520 560 600 640 580 720 760 800 Wavelength (nm) Wavelength: 418.48 nm ю 0 <u>— 20</u> 16.05 е.3 90 0 0 R/T: 0.38 Configure Graph D 0 _____ 5000 942.09 nm n-> A-2.368E0 B-3.157E4 C-3.948E8 Change n k > k0=1.605E-2 D=1842 Change k Ok 🖲 Substrate: Glass 👘 🔵 Substrate: Air Experiment Help About Exit

Figure 6 : Joptics windows showing T and R spectrum of absorbing material at normal incidence; (A) The refractive index n window, (B) The extinction coefficient k window.



Interferences in Thin-Film Coating	B2	
ransmission and Reflection Phase	e Difference	Spectrum T Maxima and Minima
	R(549.9) = 0.22 T(549.9) = 0.12	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$
Thickness 0 Vavelength 400	3000 <u>150</u> nm 800 <u>550</u> nm	0.3 0.2 0.1 400 440 480 520 560 600 640 680 720 760 Longitud d'ona (nm)
igle of incidence 0	90 45 0	Wavelength: 402.64 nm R/T: 0.34
n -> A=2.368E0 B=3.157E4 C=0E k -> k0=1.605E-2 D=1842	0 Change n Change k	Configure Graph
Substrate: Glass O Substrate: Glass	ubstrate: Air	
Substrate: Glass Substrate: Glass	ubstrate: Air Experiment He	elp About Exit
Substrate: Glass Substrate: Glass Interferences in Thin-Film Coating Transmission and Reflection Phase	ubstrate: Air Experiment He gs e Difference	elp About Exit Spectrum T Maxima and Minima
• Substrate: Glass • Substrate:	Experiment He gs Experiment e Difference Image: Comparison of the second s	elp About Exit Spectrum T Maxima and Minima
• Substrate: Glass • Substrate:	Experiment He Esperiment He Esperiment He B Difference B) = 2.59π ransmitted rays thin film B 3000 150 nm B 800 550 nm	elp About Exit
Substrate: Glass Substrate: Glass Interferences in Thin-Film Coatin Transmission and Reflection Phase $\Delta = 2.47$ Phase <t< td=""><td>Experiment He Esperiment He gs E e Difference Image: second second</td><td>elp About Exit Spectrum T Maxima and Minima</td></t<>	Experiment He Esperiment He gs E e Difference Image: second	elp About Exit Spectrum T Maxima and Minima

Figure 7 : Joptics windows showing; (A) T and R spectrum of absorbing material at oblique incident of light, (B) phase difference of light from absorbing material at oblique incident of light.

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🕹 Interferences in Thin-Film Coatings	
Transmission and Reflection Phase Difference $n_{-}=1$ θ $k_{-}=0E0$ θ $n_{-}=1.52$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 1\pi$ $\Delta = Phase difference between transmitted rays \theta = ray angle inside the thin film Thickness 0 3000 nm Wavelength 400 800 550 nm Angle of incidence 90 0 \circ $	Spectrum T Maxima and Minima 0.9 0.9 0.8 - 0.7 - 0.6 -
n -> A=1E0 B=0E0 C=0E0 Change n k -> k0=0E0 D=0 Change k Substrate: Glass Substrate: Air	Configure Graph
Experiment	ADOUR EXIT
Transmission and Reflection Phase Difference $n_l=1.38$ θ $n_l=1.38$ θ $n_s=1.52$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 2 \cdot \pi / \lambda \cdot 2 \cdot n \cdot d \cdot \cos(\theta) + \pi = 2\pi$ $\Delta = 1.38 = 0 \text{ for a state of the thin film Wavelength 400 90 550 A = 1.38 = 0 \text{ B} = 0 \text{ E} 0 \text{ C} = 0 \text{ C} Change n $	Spectrum T Maxima and Minima 0.9 0.9 0.8 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.6 0.7 0.7 0.6 40.4 0.3 0.2 0.1 0.4 0.3 0.2 0.1 0.4 0.3 0.2 0.1 0.1 0.1 0.2 0.1 0.3 0.2 0.4 0.3 0.7 0.0 400 480 520 560 600 640 680 Wavelength: 407.92 nm R/T: 0.99 Configure Graph Configure Graph
Substrate: Glass Substrate: Air	
Experiment Help	About Exit

Figure 8 : Joptics windows showing the the phase difference (normal incidence); (A) glass substrate, (B) MgF₂ on glass of geometrical thickness d=99.637 nm at $\lambda_0 = 550$ nm.



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🛎 Interferences in Thin-Film Coatings	
Transmission and Reflection Phase Difference R(549.9) = 0.22	SpectrumT Maxima and Minima λ = 728 nm, k = 2, Max. λ = 500 nm, k = 3, Min.
↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓	
Thickness 0 3000 150 nm	
Angle of incidence 0 90 0 0	
n -> A=2.368E0 B=3.157E4 C=3.948E8 Change n k -> k0=1.605E-2 D=1842 Change k	 Variable: Wavelength Variable: Angle
Experiment	About Exit

Figure 9 : Joptics windows showing $T_{max and min}$ window of absorbing material at normal incidence.

Range R" and "Auto Range T" assign automatically the minimum R/T range that permits representing the spectra of R or T respectively as shown in Figure 4-a.

(d) Window 'T Maxima and Minima'

This window shows a list of the Transmittance maxima and minima that can be seen in the spectrum plot. The option "Variable: Wavelength" lists the maxima and minima as a function of the wavelength. This list is calculated for the values of $n(\lambda)$, $k(\lambda)$ and thickness of the film and for the selected angle of incidence. The option "Variable: Angle" the list is calculated as a function of the angle of incidence for the wavelength selected on the left window, shown in Figure 9.

(e) The virtual experiment: the button 'Experiment'

The button "Experiment" simulates an experimental situation where a sample composed of a substrate with a transparent (k=0) thin-film coating on top of it. The thickness and refractive index of the thin-film are unknown and they have to be deduced from the analysis of a spectrum taken with a spectrometer. The window "Spectrum" shows two spectra (in blue and in yellow, R exp and T exp) that correspond to the unknown sample and two spectra corresponding to the model with the current selected values. The virtual experiment consists of finding out the values of thickness d and of the variables A and B which characterize the spectral behavior of the refractive index. To change the values of A and B the button "Change n" should be used. The procedure to find the correct values is that of trial and error: 1) try to change the value of one of these parameters, 2) check whether the theoretical spectra fit better or not the experimental ones and 3) decide if the change in the parameter is in the right sense or not. This can be shown in Figure 10.

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Figure 10: Joptics windows EXPERIMENTAL window of absorbing material at normal incidence.



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Examples

To illustrate Joptics applets, normal and oblique incident of light on thin film material were consider as an examples taking into account the followings:

- Choosing glass as substance with index n=1.52 at $\lambda_0 = 550$ nm.shown Figure 4
- Choosing MgF₂ as dielectric material with index $n_f=1.38$ at $\lambda_0 = 550$ nm, with optical thickness of quarter-wavelength (geometrical thickness $d_f=99.64$ nm).as in Figure 5
- Absorbing material taking in to account dispersion of n and k.Figure 6.
- Phase shift due to reflection. shown in Figure 7 and 8.
- R_{exp} and T_{exp} of unknown thickness and refractive index in laboratory.shown in Figure 10.

CONCLUSION

There are at least many ways that Java applets can be used in education:

- 1. teachers can perform classroom demonstrations involving real-time computations, bringing more realism to the subject matter.
- 2. Can encourage asynchronous distance learning and thus help overcome the limitations (involving both time and space) inherent in traditional instructional techniques.
- 3. when used in a classroom, can bring a stronger integration between (already existing) theoretical and practical aspects of the subject.
- 4. This applets may be consider as :
 - informational applets which are similar to the

Help files in Windows-based programs where by clicking on a tab or choosing an item from a pull-down menu, the user can obtain more information on the topic.

- concept illustrating applets.
- Computational Applets, can serve as examples of concepts being learnt as well as illustrating a phenomena. They can have the capability of user-interactive visualization of results and with a built-in graphical user interface (GUI) to facilitate experimentation by manipulating various parameters which can be "hard-wired".
- 5. The applet can be used either in an ordinary course as support material or as the main working tool in an on-line Internet course.

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