A PORTRAIT OF

RONALD FUCHS

ON HIS 75th BIRTHDAY

" in recognition for his contributions to nonlocal optics and optical properties of small particles and his fruitful collaborations with Latin American physicists"

Rubén G. Barrera

Instituto de Física, UNAM

Ronald Fuchs

Personal History

1932	(00)	Born in LA California	
1954	(22)	BS California Institute of Technology	
1957	(25)	PhD University of Illinois (Champaign-Urbana)	
1958	(26)	PosDoc Massachusetts Institute of Technology	
1958	(26)	First paper	
1961	(29)	Assistant Professor ISU & Ames Lab	
1966	(34)	Associate Professor ISU & Ames Lab	
1973	(41)	Visiting Professor Max Planck, Stuttgart	
1974	(42)	Full Professor ISU & Ames Lab	
1981	(49)	First collaboration with Latin American physicists	
1986	(52)	Visiting Professor Freie Universität Berlin	
1996	(62)	Professor Emeritus Iowa State University	(23)
1996	(62)	Overseas Fellow Cambridge University	
2004	(72)	Last collaboration with Latin American physicists	
2006	(74)	A paper in PRB	

Research interests

Theory of the optical properties of metals and insulators:
thin films, small particles, rough surfaces, disordered systems,
non-local effects, surface reflectance spectroscopy.
Electron energy-loss spectroscopy of inhomogeneous systems.

Ames Lab

Iowa State University

Main contributions

PHYSICAL REVIEW VOLUME 172, NUMBER 3 15 AUGUST 1968

Anomalous Skin Effect for Specular Electron Scattering and Optical Experiments at Non-Normal Angles of Incidence*

K. L. Kliewer and Ronald Fuchs
Institute for Atomic Research and Department of Physics, Iowa State University, Ames, Iowa 50010

Received 14 March 1968

The anomalous skin effect for specular electron scattering at the metal surface is studied, permitting the impinging plane wave to have an arbitrary angle of incidence. It is shown that the expressions for the surface impedance for a non-normal angle of incidence obtained by Reuter and Sondheimer as a generalization from their work at normal incidence are correct for S polarization but incorrect for P polarization. The correct surface impedance for P polarization leads to an additional absorption peak in the frequency range $10^{-2}\omega_p \lesssim \omega \lesssim \omega_p$, where ω_p is the free-electron plasma frequency. This additional absorption, particularly pronounced for long electron lifetimes, is investigated in detail. One important conclusion drawn from this work is that, in general, optical experiments performed at non-normal angles of incidence cannot be analyzed in terms of a single complex frequency-dependent dielectric function. In the frequency range of the additional P absorption, two such dielectric functions are needed, one function for describing P polarization and a different function for describing S polarization.

I. INTRODUCTION

THE theory by which the anomalous skin effect was incorporated into the general theory of the optical properties of metals was developed in detail by

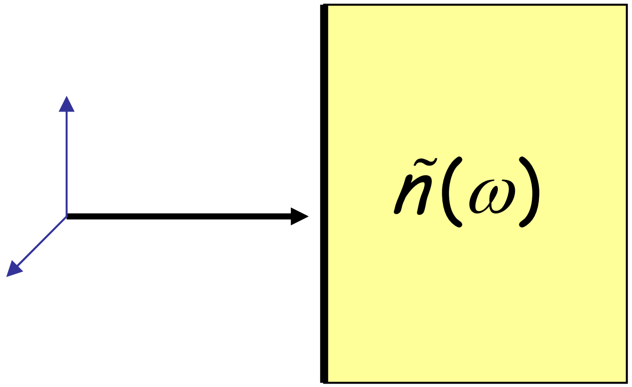
Mattis and Bardeen[3]; their result for the surface impedance was in agreement with that of Reuter and Sondheimer.

A recent study of the classical optical properties of

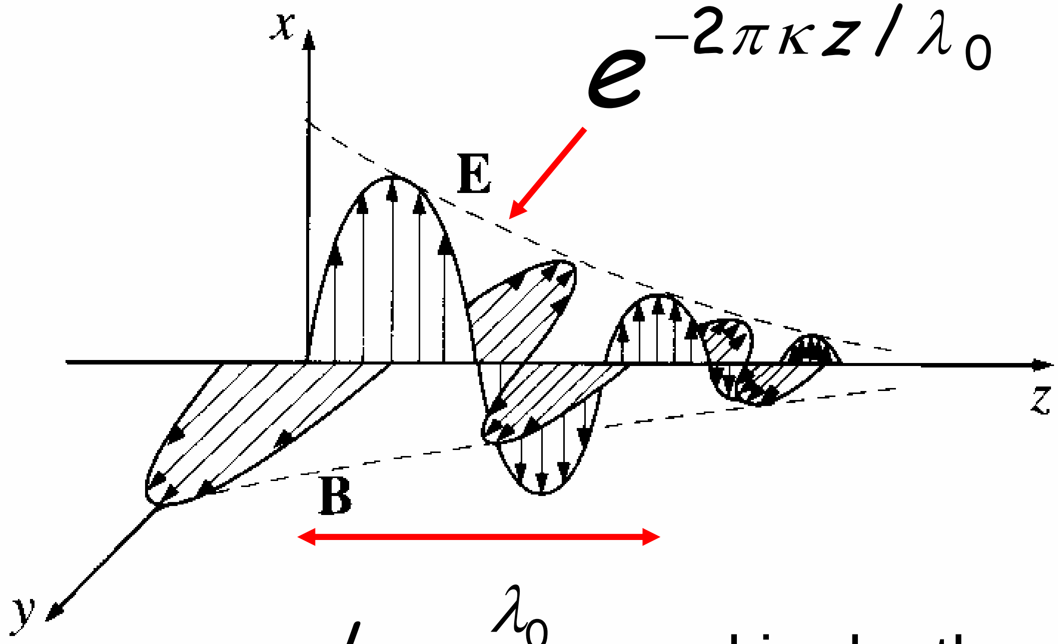
Skin effect

$$\tilde{n}(\omega) = n(\omega) + i\kappa(\omega)$$

"absorption"



$$e^{-2\pi\kappa z/\lambda_0}$$



$$l_p = \frac{\lambda_0}{2\pi\kappa}$$ skin depth

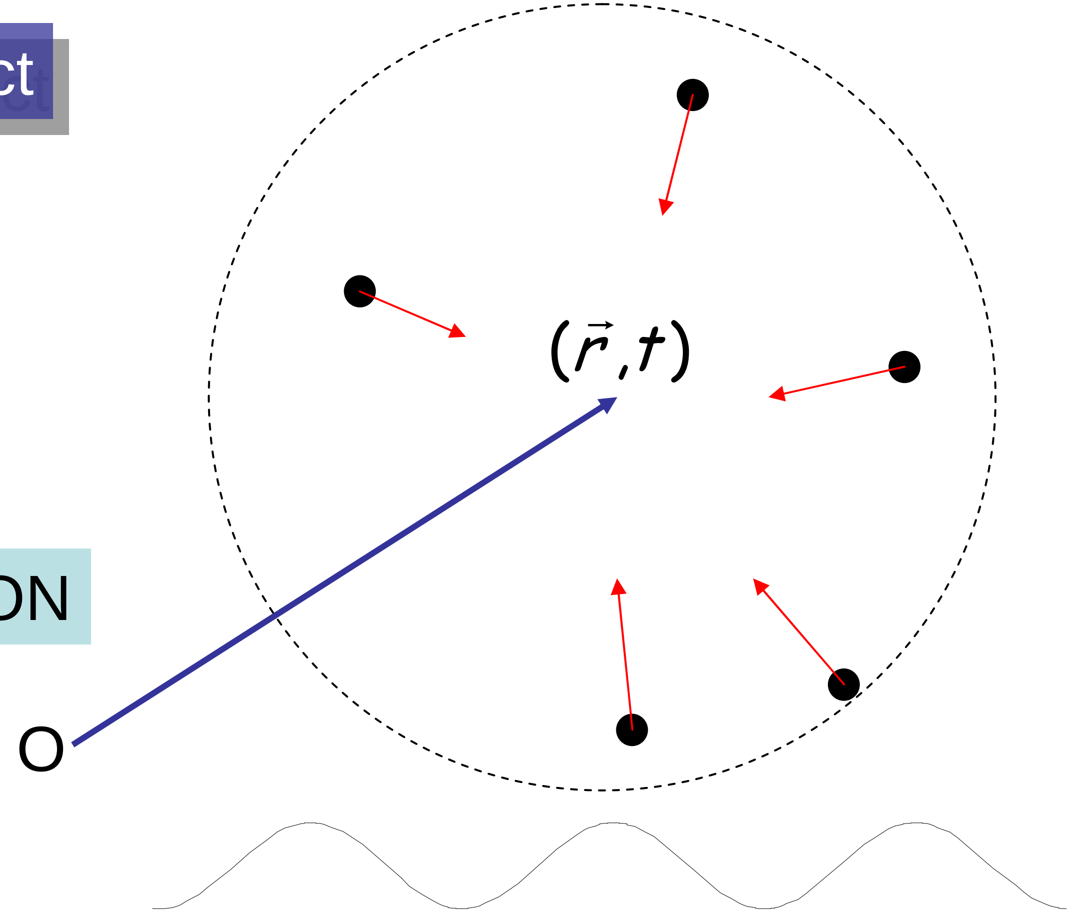
$$l_p \gg l_{mfp}$$

Anomalous skin effect

$$l_p < l_{mfp}$$

SPATIAL DISPERSION

NON-LOCAL



$$\vec{J}(\vec{r};\omega) = \int \overleftrightarrow{\sigma}(\vec{r},\vec{r}\,';\omega)\cdot\vec{E}(\vec{r}\,';\omega)\,d^3r'$$

p-representation

Bulk

$$\vec{J}(\vec{r};\omega) = \int \overleftrightarrow{\sigma}(\vec{r}-\vec{r}';\omega)\cdot\vec{E}(\vec{r}';\omega)\,d^3r'$$

$$\Downarrow$$

$$\vec{J}(\vec{p},\omega) = \overleftrightarrow{\sigma}(\vec{p},\omega)\cdot\vec{E}(\vec{p},\omega)$$

$$\overleftrightarrow{\varepsilon}(p,\omega) = \overleftrightarrow{1} + \frac{i}{\omega}\overleftrightarrow{\sigma}(p,\omega)$$

isotropic

$$\overleftrightarrow{\varepsilon}(p,\omega) = \hat{p}\hat{p}\,\varepsilon^L(p,\omega) + (\overleftrightarrow{1} - \hat{p}\hat{p})\,\varepsilon^T(p,\omega)$$

Dielectric approach

$$\epsilon_t = 1 - \frac{1}{\Omega(\Omega+i\gamma)} \frac{3}{2} \frac{1}{(b'Q)^3} \times \left[\frac{\{(b'Q)^2+1\}}{2i} \ln\left\{\frac{1+ib'Q}{1-ib'Q}\right\} - b'Q \right] \quad (2.46)$$

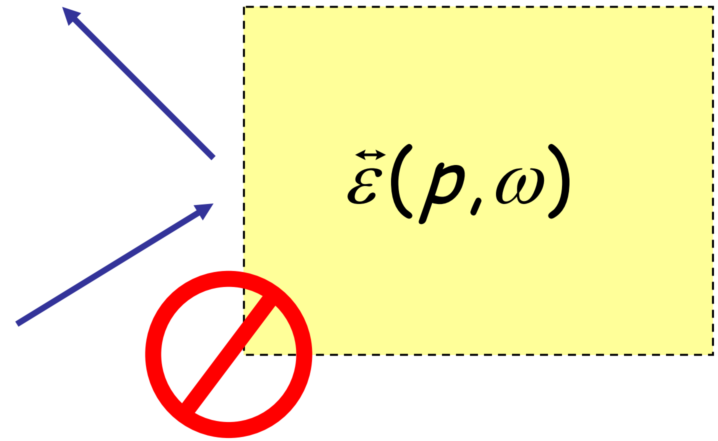
[12] The surface impedance is defined by $Z_P = (4\pi/c)(E_x/H_y)$. However, in the case of optical properties the important quantity is $(c/4\pi)Z_P$. Thus, to avoid useless repetition of factors $(c/4\pi)$, we call E_x/H_y the surface impedance but denote it by Z_P' to remind the reader that the definition is not the normal one. A similar convention will be used below for S polarization with $Z_S' \equiv -E_y(0+)/H_x(0+)$.

ever, in Sec. III a more adroit scheme is presented for the determination of the surface impedance and a discussion of Z_S' will be deferred to that point.

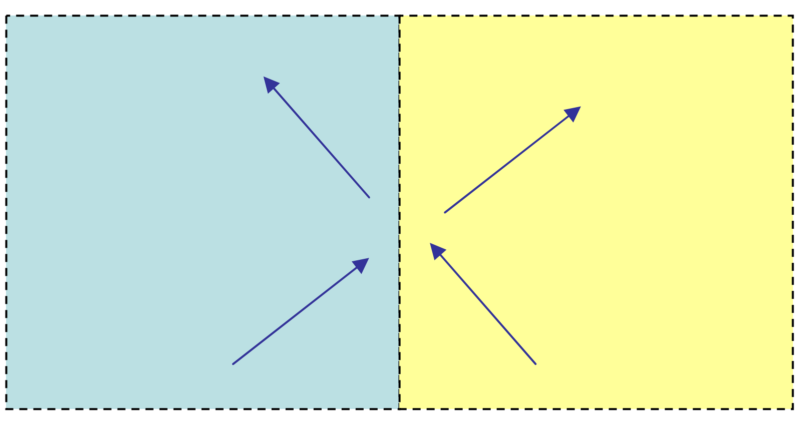
III. THEORY: DIELECTRIC-CONSTANT APPROACH

In the calculation of the surface impedance at non-normal incidence presented in Sec. II, the Boltzmann equation was used to solve for the current **J** in terms of the field **E** in the presence of a boundary. An alternative procedure will be used in this section to derive the sur-

Reflection



SCIB



specular symmetry

$$D_x(x,y,z) = D_x(x,y,-z)$$

$$D_z(x,y,z) = -D_z(x,y,z)$$

Thus Eq. (3.11) finally becomes

$$\frac{\mathcal{E}_x}{H_y(0+)}=\frac{2i\omega}{cq^2}\left[\frac{q_x^2}{(\omega^2/c^2)\epsilon_l}+\frac{q_z^2}{(\omega^2/c^2)\epsilon_t-q^2}\right]. \tag{3.14}$$

The inverse Fourier transform of Eq. (3.14) evaluated at $z=0$ gives

$$Z_P'\equiv\frac{E_x(0+)}{H_y(0+)}=\frac{2i\Omega}{\pi}\int_0^\infty\frac{dQ_z}{Q^2}\left[\frac{Q_x^2}{\Omega^2\epsilon_l}+\frac{Q_z^2}{\Omega^2\epsilon_t-Q^2}\right] \tag{3.15}$$

in terms of the dimensionless variables defined in Eqs. (2.43). Equation (3.15) is the same as Eq. (2.44); however, ϵ_l and ϵ_t are as yet unspecified. This result therefore has a general validity independent of the particular model used for obtaining ϵ_l and ϵ_t. The only requirement is that $\epsilon_l(\mathbf{q},\omega)$ and $\epsilon_t(\mathbf{q},\omega)$ exist.[13] In the present context, the appropriate value of ϵ_t is that of Eq. (2.46), whereas ϵ_l is correctly given by (2.47). However, were the relaxation to the perturbed state not to be considered, ϵ_l would be given by ϵ_w, Eq. (2.49).[14]

S Polarization

$=-(i\omega/c)H_x$, Eq. (3.18) follows immediately. Since the electric field is perpendicular to $\mathbf{q}$ for S polarization,

$$\mathfrak{D}_y=\epsilon_t\mathcal{E}_y. \tag{3.19}$$

Using Eq. (3.19), we solve Eq. (3.18) for $\mathcal{E}_y/H_x(0+)$:

$$\frac{\mathcal{E}_y}{H_x(0+)}=-\frac{2i\omega}{c}\frac{1}{(\omega^2/c^2)\epsilon_t-q^2}. \tag{3.20}$$

The inverse Fourier transform of Eq. (3.20) evaluated at $z=0$ gives

$$Z_S'\equiv-\frac{E_y(0+)}{H_x(0+)}=\frac{2i\Omega}{\pi}\int_0^\infty\frac{dQ_z}{\Omega^2\epsilon_t-Q^2}, \tag{3.21}$$

where the dimensionless variables defined in Eqs. (2.43) have again been introduced. The appropriate expression for ϵ_t is that of Eq. (2.46).

Reflectance

For completeness, we shall present expressions for the reflectance in terms of the surface impedance. The fields associated with the incident and reflected waves for P polarization are of the following form:

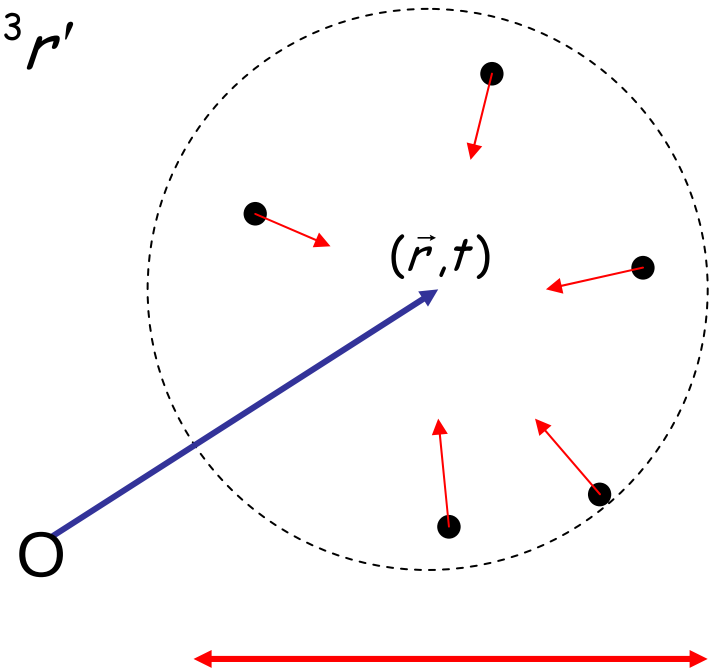
Local limit

$$\vec{J}(\vec{r};\omega) = \int \overleftrightarrow{\sigma}(\vec{r},\vec{r}\,';\omega)\cdot\vec{E}(\vec{r}\,';\omega)\,d^3r'$$

Local limit

$$\vec{J}(\vec{r};\omega) \approx \left[\int \overleftrightarrow{\sigma}(\vec{r},\vec{r}\,';\omega)\,d^3r'\right]\cdot\vec{E}(\vec{r}\,';\omega)$$

$$\underbrace{\left[\int \overleftrightarrow{\sigma}(\vec{r},\vec{r}\,';\omega)\,d^3r'\right]}_{\overleftrightarrow{\sigma}(\vec{r};\omega)}$$



$$l_{NL} \ll \lambda_0$$

metal

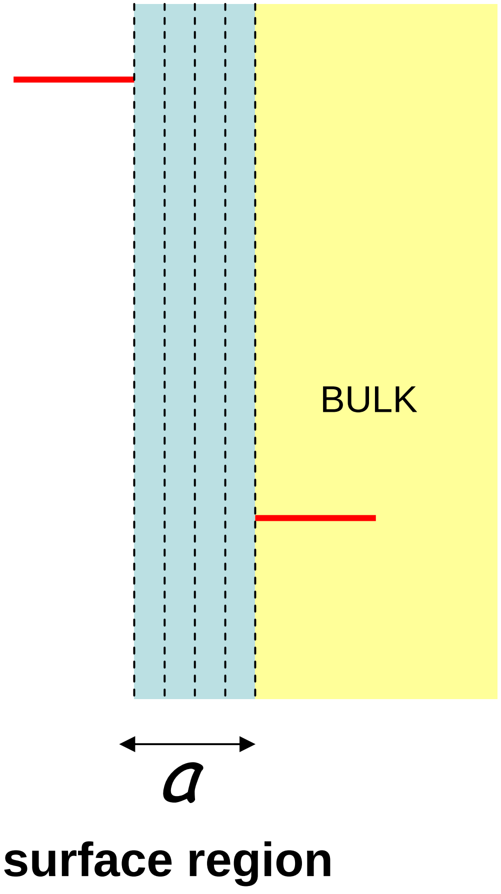
$$l_{NL} \approx \frac{v_F}{\omega} = \frac{(v_F / c)}{2\pi}\lambda_0$$

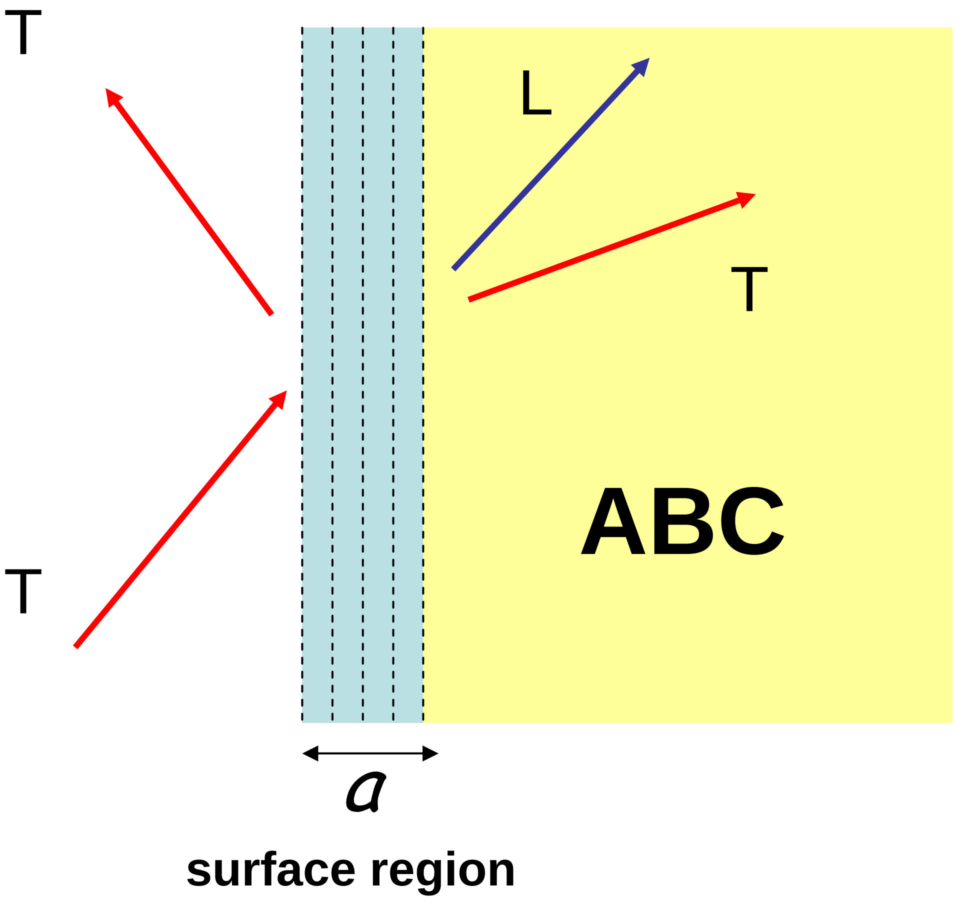
Non-local optics

metals
excitonic semiconductors

$$E_z$$

$$\varepsilon^L(p,\omega) = 0$$





Small particles

PHYSICAL REVIEW B VOLUME 11, NUMBER 4 15 FEBRUARY 1975

Theory of the optical properties of ionic crystal cubes

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(Received 11 March 1974; revised manuscript received 4 September 1974)

A theory is developed for the optical properties of particles of arbitrary shape, composed of a homogeneous isotropic material with a dielectric constant $\epsilon(\omega)$. The particles are so small that retardation can be neglected. An expression is obtained for the average dielectric constant of a medium containing a small fractional volume of particles. Calculations for a cube show that six resonances contribute to the optical absorption. They span a frequency range such that $\epsilon'(\omega)$, the real part of the dielectric constant, lies between -3.68 and -0.42, as contrasted with the single resonance for a sphere at $\epsilon'(\omega) = -2$. A comparison of the theory with experiments on the optical absorption of NaCl and MgO cubes shows that the width of the absorption peak can be explained by the frequency range of the cube resonances. Previous theories which assumed spherical particles required an unphysically high damping in $\epsilon(\omega)$ to account for the width.

I. INTRODUCTION

The optical properties of spherical metallic or dielectric particles are well understood, and the

The theory is applied to a cube in Sec. V, and in Sec. VI a comparison is made with experiments.

Small cube

Spectral representation (for any shape)

$$\frac{\alpha_{\alpha\beta}(\omega)}{v} = \sum_m \frac{C_{\alpha\beta}(m)}{\chi^{-1}(\omega) + 4\pi n_m}$$

TABLE I. Values of $C(m)$, n_m, and $\epsilon'(\omega)$ for the six major absorption peaks of a cube. $\epsilon'(\omega)$, the value of the real part of the material dielectric function at each absorption peak, is given by $\epsilon'(\omega) = 1 - n_m^{-1}$.

m	$C(m)$	n_m	$\epsilon'(\omega)$
1	0.44	0.214	−3.68
2	0.24	0.297	−2.37
3	0.04	0.345	−1.90
4	0.05	0.440	−1.27
5	0.10	0.563	−0.78
6	0.09	0.706	−0.42

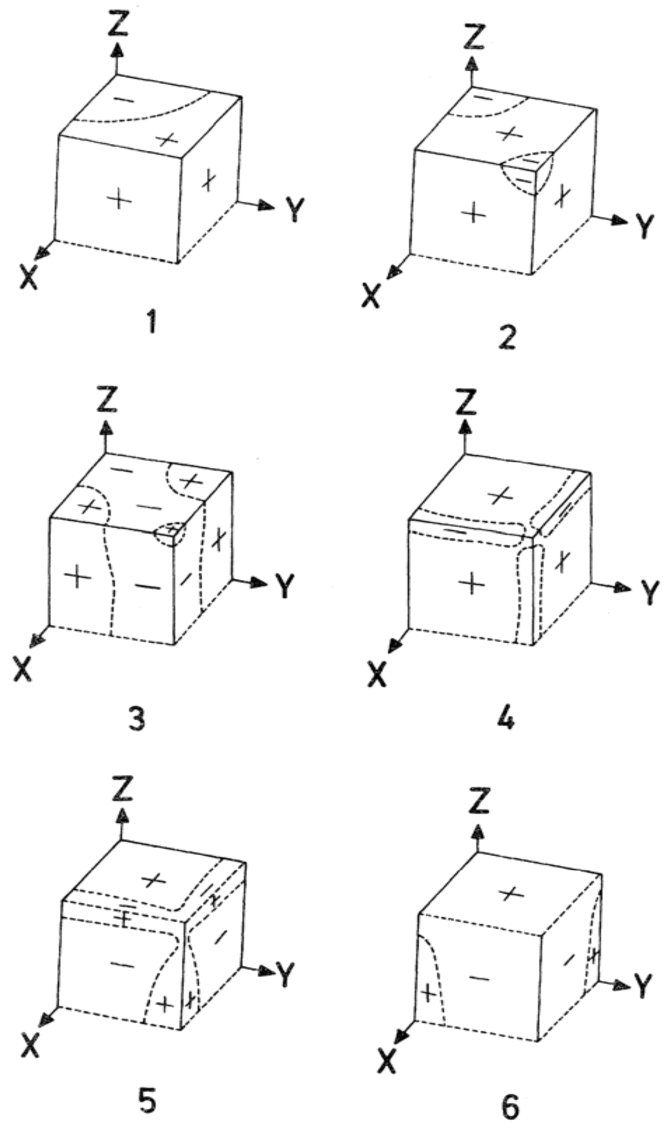

FIG. 1. Normal modes corresponding to the six major absorption peaks of a cube. The numbering corresponds to that of Table I.

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Spectral representation

For any shape

granular composite
(colloid)

$$\frac{\varepsilon_M}{\varepsilon_2} = 1 - f\int_0^1 \frac{g(n)}{u-n}\,dn$$

$$\frac{1}{1-\left[\varepsilon_1(\omega)/\varepsilon_2(\omega)\right]}$$

EELS

provide an expression of $\varepsilon^{-1}(k,\omega)$ as a series of simple poles and residues. We obtain

$$\varepsilon^{-1}(k,\omega)=(\varepsilon_2)^{-1}\left[1+f\left[\frac{C_b}{u-1}+\sum_s \frac{C_s}{u-n_s}\right]\right], \qquad (27)$$

where f is the volume fraction of the spherical particles and u is a spectral variable, defined as

$$u=-(\varepsilon_1/\varepsilon_2-1)^{-1}\,. \qquad (28)$$

Here we have replaced $\varepsilon^{-1}(k,\omega)$ by $\varepsilon^{-1}(k,\omega)\varepsilon_2$ and ε by

Key words

Spatial dispersion

Nonlocal

Spectral representation

Additional Boundary Conditions (ABC)

Collaborations with Latin American physicists

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Publications

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PUEBLA

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SANTIAGO

School of thought

Spatial dispersion

Nonlocal

Spectral representation

SYMPOSIUM IN HONOR OF PROFESSOR

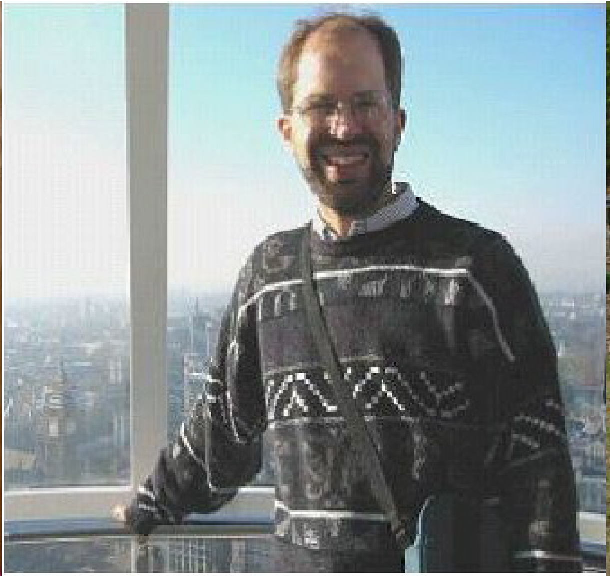
RONALD FUCHS

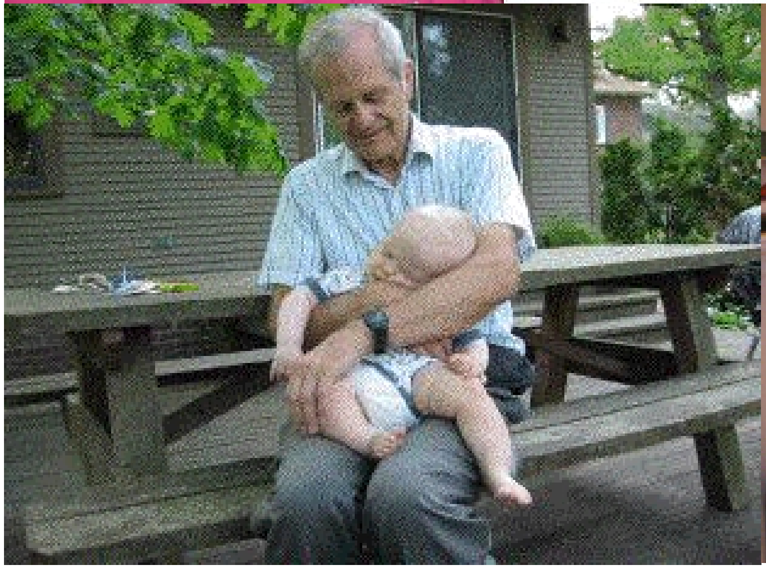
To be held on Tuesday November 21, 2006
within the Simposio Latinoamericano de
Física del Estado Sólido (**SLAFES06**)
at the city of Puebla, Mexico

9:10	9:25	**OPENING**
9:25	10:05	Carlos Mendoza “Study of electro-optic effects in confined nematic liquid crystals: A geometrical optics approach”
10:05	10:45	Rubén G. Barrera “Use and abuse of the effective refractive index in colloidal systems: Nonlocal effects”
10:45	11:15	**COFEE BREAK**
11:15	11:55	Peter Halevi “A spatially dispersive description of photonic metamaterials I”
11:55	12:35	Felipe Pérez “A spatially dispersive description of photonic metamaterials II”
12:35	13:15	José Luis Carrillo “Aggregation processes and physical properties of complex condensed matter systems”
13:15	16:25	**LUNCH**
16:25	17:05	Luis Mochán “Non Locality in the Casimir Effect”
17:05	17:45	Gregorio Hernández Cocoletzi “First principles total energy calculations of phase transitions of silver halides”
17:45	18:15	**COFEE BREAK**
18:15	18:55	Francisco Claro “Nonlocal effects of a bad cold”
18:55	19:35	Ronald Fuchs Title to be announced
20:30	22:30	**DINNER**

The man

HIS FAMILY




Music

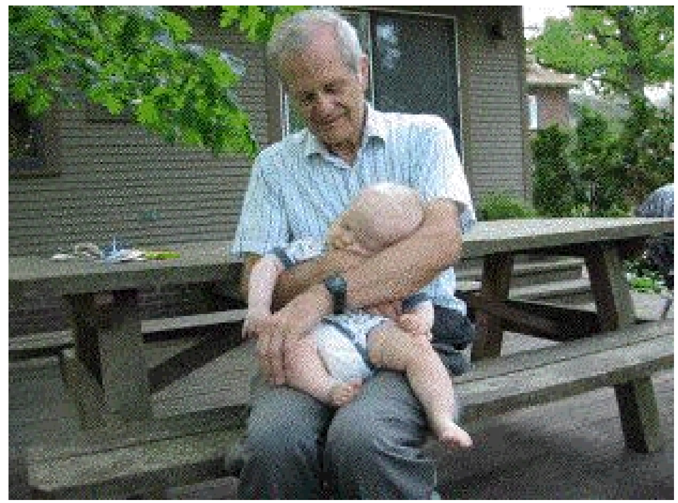
SCOTTISH COUNTRY DANCERS OF CENTRAL IOWA

Squaw Creek Recorder Ensemble

Sports

Popocatépetl **3 marathons**

RON



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CONGRATULATIONS