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THE INTERACTION ENERGIES OF CHOLESTEROL AND LECITHIN IN SPREAD MIXED MONOLAYERS AT THE AIR-WATER INTERFACE

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SUMMARY

1. The interaction between dilauroyl lecithin, diundecyloyl lecithin, didecanoyl lecithin and dinonanoyl lecithin with cholesterol was investigated using the Goodrich method. No interaction with cholesterol was found for dinonanoyl lecithin, while with didecanoyl lecithin small effects could be detected only at high surface pressure. Strong condensation effects occurred with diundecyloyl lecithin and dilauroyl lecithin. The pressure-area curves of these lecithins are given.

2. Assuming a regular surface mixture, a theory was derived which allows one to describe the collapse pressure of a mixed monolayer with miscible components.

3. The interaction between distearoyl lecithin, dipalmitoyl lecithin, dimyristoyl lecithin, dilauroyl lecithin, diundecyloyl lecithin, didecanoyl lecithin, dinonanoyl lecithin, oleoyl-stearoyl lecithin, dioleoyl lecithin and dilinoleoyl lecithin with cholesterol was investigated by measuring the collapse pressure of the mixed monolayers. An interaction parameter and interaction energies were calculated.

4. According to this method distearoyl lecithin, dipalmitoyl lecithin, dinonanoyl lecithin and dilinoleoyl lecithin showed no interaction with cholesterol; while dimyristoyl lecithin, dilauroyl lecithin, diundecyloyl lecithin, oleoyl-stearoyl lecithin and dioleoyl lecithin interacted markedly with cholesterol. A small effect was observed for didecanoyl lecithin.

The most pronounced effect was observed for dilauroyl lecithin and oleoyl-stearoyl lecithin.

5. The results obtained using the Goodrich and collapse pressure methods are in good agreement.

INTRODUCTION

In view of the presence of cholesterol in most biological membranes, the interaction between cholesterol and phospholipids has been extensively studied in several model systems, particularly by monolayer techniques[1–6]. After the pioneer work of DE BERNARD[7] who used a natural lecithin, attention was focused on the pure synthetic phospholipids[8]. These cholesterol-phospholipid interactions were mainly investigated by considering the mean molecular areas of the components at a certain pressure

(Goodrich method)[9]. It has clearly been shown[8] that the interaction between cholesterol and phospholipids is closely related to the nature of the fatty acid chains present in the phospholipid molecule. However, there is some disagreement between the various investigators in explaining the reduction in mean molecular area[3,6,8]. The method of spreading monolayers containing cholesterol and phospholipid is confined to the air–water interface because of the solubility of cholesterol in an oil phase. Absorbed monolayers of cholesterol and lecithin at the oil–water interface enabled us to show[10] that the phospholipid–cholesterol interaction is mainly due to Van der Waals–London attraction forces. Recently one of us[11] derived a thermodynamic relation, which allows the collapse pressure of an insoluble monolayer of miscible components to be calculated as a function of the composition, when no interaction occurs (ideal behavior).

Although some preliminary results were obtained[8] about the magnitude of the cholesterol–phospholipid interaction (using the Goodrich method), the present method of calculating the collapse pressures of mixed films yields some further information about these interaction energies. In this paper the theory will be further elaborated and applied to systems of cholesterol and synthetic lecithins with fatty acid chains ranging from 9 to 18 carbon atoms. The results obtained by the Goodrich method and by the method of calculating collapse pressures will be compared.

THEORY

In a previous paper[11] it was shown that the collapse pressure of a mixed insoluble monolayer with completely miscible components is given by the relation:

$$1 = \overset{\mathrm{s}}{x}_1\gamma_1 \exp\left(\frac{\pi_{\mathrm{c,m}} - \pi_{\mathrm{c,1}}}{kT}\,\omega_1\right) + \overset{\mathrm{s}}{x}_2\gamma_2 \exp\left(\frac{\pi_{\mathrm{c,m}} - \pi_{\mathrm{c,2}}}{kT}\,\omega_2\right) \qquad (1)$$

where x_1^{s}, x_2^{s} represent the mole fraction at the surface (at the collapse point) of Components 1 and 2, respectively; $\pi_{\mathrm{c,1}}$, $\pi_{\mathrm{c,2}}$ represent the collapse pressure of Components 1 and 2, respectively; $\pi_{\mathrm{c,m}}$ represents the collapse pressure of the mixed monolayer at a given composition of the surface (x_1^{s}; x_2^{s}); ω_1, ω_2 represent the cross section (limiting molecular area) at the collapse point of Components 1 and 2, respectively; and γ_1,γ_2 represent surface activity coefficients at the collapse point of Components 1 and 2, respectively.

If no interaction occurs, surface activity coefficients will be equal to unity ($\gamma_1 = 1$; $\gamma_2 = 1$), and the theoretical curve should coincide with the experimental one. Hence it is possible to consider the occurrence of an interaction between Components 1 and 2 by comparing the experimental points with the theoretical curve calculated according to Eqn. 1, assuming that the activity coefficient is equal to unity. When the surface mixture shows ideal behavior and the collapse pressures of the two components are not very different, the exponentials in Eqn. 1 may be expanded in series, and the following approximate relation is obtained:

$$\pi_{\mathrm{c,m}} = \overset{\mathrm{s}}{x}_1\pi_{\mathrm{c,1}} + \overset{\mathrm{s}}{x}_2\pi_{\mathrm{c,2}} \qquad (1')$$

When an interaction occurs, surface activity coefficients must be accounted for. The simplest case is to assume a regular behavior. Denoted by ε_{ij} in which the potential energy of interaction between a molecule of type i and one of type j, the energy of mixing, W, is given by (ref. 12, Eqn. 12.78):

$$W = nz\left(\varepsilon_{12} - \frac{\varepsilon_{11} + \varepsilon_{22}}{2}\right) x_1^s x_2^s = n\alpha\, x_1^s x_2^s \tag{2}$$

where n is total number of moles and z is number of nearest neighbors. According to DEFAY *et al.* (ref. 12, Eqn. 12.89), the chemical potential of Components 1 and 2 in the surface is given by:

$$\begin{aligned} \mu_1^s &= \zeta_1^s + kT \ln x_1^s + \alpha l (x_2^s)^2 + \alpha m (x_2^B)^2 + \pi\omega_1 \\ \mu_2^s &= \zeta_2^s + kT \ln x_2^s + \alpha l (x_1^s)^2 + \alpha m (x_1^B)^2 + \pi\omega_2 \end{aligned} \tag{3}$$

where x_1^B, x_2^B are the mole fractions of Components 1 and 2 in the bulk solutions; lz is the fraction of nearest neighbors in the surface; mz is the fraction of nearest neighbors in the bulk; z is the number of nearest neighbors in the three dimensions ($l + 2m = 1$); and ζ_1^s, ζ_2^s are the standard chemical potentials of Components 1 and 2, respectively. Since we are dealing with insoluble monolayers, x_1^B and x_2^B are nearly zero; hence Eqn. 3 becomes (ref. 12, Eqn. 14.23):

$$\begin{aligned} \mu_1^s &= \zeta_1^s + kT \ln x_1^s + \alpha l (x_2^s)^2 + \pi\omega_1 \\ \mu_2^s &= \zeta_2^s + kT \ln x_2^s + \alpha l (x_1^s)^2 + \pi\omega_2 \end{aligned} \tag{3'}$$

On the other hand, the surface activity coefficients, γ_1 and γ_2, are defined by the relation (ref. 12, Eqn. 14.13; ref. 13):

$$\mu_i^s = \zeta_i^s + kT \ln \gamma_i x_i^s + \pi\omega_i \tag{4}$$

From Eqns. 3′ and 4 we deduce:

$$\begin{aligned} \gamma_1 &= \exp\left[\xi (x_2^s)^2\right] \\ \gamma_2 &= \exp\left[\xi (x_1^s)^2\right] \end{aligned} \tag{5}$$

where

$$\xi = \frac{\alpha l}{kT} \tag{5'}$$

The surface activity coefficients, as defined by Eqn. 5 in the case of a regular surface solution, satisfy the Gibbs–Duhem restriction[14]:

$$x_1^s \,\mathrm{d} \ln \gamma_1 + x_2^s \,\mathrm{d} \ln \gamma_2 = 0 \tag{6}$$

as can be easily shown.

Substitution of the surface activity coefficients γ_1, γ_2, as given in Eqn. 5, into Eqn. 1 yields:

$$1 = x_1^s \exp\left(\frac{\pi_{c,m} - \pi_{c,1}}{kT}\,\omega_1\right) \exp\left[\xi (x_2^s)^2\right] + x_2^s \exp\left(\frac{\pi_{c,m} - \pi_{c,2}}{kT}\,\omega_2\right) \exp\left[\xi (x_1^s)^2\right] \tag{7}$$

Thus, one can try to fit Eqn. 7 to the experimental curve by adjusting the interaction parameter ξ. However, this exponential equation is difficult to solve. As will be seen in our results, an extreme value of the collapse pressure as a function of the composition may be obtained. This extreme value is analogous to an azeotrope. In our cases it was rather difficult to say exactly at which composition this azeotrope occurred, but the magnitude of this azeotrope may be assessed with some accuracy. This feature is due to the fact that the experimental curve shows a rather flat maximum. Previously it was shown that at the collapse point a second bulk phase β is formed at the surface (floating lens or crystal). At this azeotrope the composition of the surface phase and of the collapsed phase should be equal. Hence at constant p and T, a surface azeotrope is characterized by

$$\begin{aligned} (x_i^{\mathrm{s}})_{\mathrm{az}} &= (x_i^{\beta})_{\mathrm{az}} \\ \left(\frac{\mathrm{d}\,\pi_{\mathrm{c,m}}}{\mathrm{d}\,x_i^{\mathrm{s}}}\right)_{\mathrm{az}} &= 0 \end{aligned} \tag{8}$$

where in the suffix az indicates that this relation holds for azeotropes.

The chemical potential of the ith component in the collapse phase β and in the surface phase should be equal; hence

$$\zeta_i^{\beta} + kT \ln x_i^{\beta} = \zeta_i^{\mathrm{s}} + kT \ln \gamma_i x_i^{\mathrm{s}} + \pi_{\mathrm{c,m}}\omega_i \tag{9}$$

for Compound 1:

$$\zeta_1^{\beta} + kT \ln x_1^{\beta} = \zeta_1^{\mathrm{s}} + kT \ln \gamma_1 x_1^{\mathrm{s}} + \pi_{\mathrm{c,m}}\omega_1 \tag{9'}$$

remembering that if $x_1^{\beta} = 1$, $x_1^{\mathrm{s}} = 1$, $\gamma_1 = 1$ and $\pi_{\mathrm{c,m}} = \pi_{\mathrm{c,1}}$ we obtain $\zeta_1^{\beta} = \zeta_1^{\mathrm{s}} + \pi_{\mathrm{c,m}}\,\omega_1$ hence

$$\zeta_1^{\mathrm{s}} - \zeta_1^{\beta} = -\pi_{\mathrm{c,1}}\omega_1 \tag{10}$$

and for Component 2:

$$\zeta_2^{\mathrm{s}} - \zeta_2^{\beta} = -\pi_{\mathrm{c,2}}\omega_2 \tag{10'}$$

Eqn. 9′ can also be written as:

$$x_1^{\beta} = \gamma_1 x_1^{\mathrm{s}} \exp\left(\frac{\pi_{\mathrm{c,m}}\omega_1}{kT}\right) \exp\left(\frac{\zeta_1^{\mathrm{s}} - \zeta_1^{\beta}}{kT}\right) \tag{11}$$

Substitution of the value of $\zeta_1^{\mathrm{s}} - \zeta_1^{\beta}$ from Eqn. 10 into Eqn. 11 yields

$$x_1^{\beta} = \gamma_1 x_1^{\mathrm{s}} \exp\left(\frac{\pi_{\mathrm{c,m}} - \pi_{\mathrm{c,1}}}{kT}\,\omega_1\right) \tag{12}$$

and

$$x_2^{\beta} = \gamma_2 x_2^{\mathrm{s}} \exp\left(\frac{\pi_{\mathrm{c,m}} - \pi_{\mathrm{c,2}}}{kT}\,\omega_2\right) \tag{12'}$$

Since $x_1^{\beta} + x_2^{\beta} = 1$, Eqn. 1 is obtained from Eqns. 12 and 12′. The first condition in Eqn. 8 gives:

$$\gamma_1 = \exp\left(\frac{\pi_{\mathrm{c,1}} - \pi_{\mathrm{c,m}}}{kT}\,\omega_1\right) = \exp\,[\zeta(x_2^{\mathrm{s}})^2] \tag{13}$$

$$\gamma_2 = \exp\left(\frac{\pi_{\mathrm{c,2}} - \pi_{\mathrm{c,m}}}{kT}\,\omega^2\right) \exp\,[\zeta(x_1^{\mathrm{s}})^2] \tag{13'}$$

(at the "azeotrope"). From Eqns. 13 and 13′ is deduced

$$\xi = \left[\frac{\pi_{c,1} - \pi_{c,m}}{kT(x^s_2)^2}\,\omega_1\right]_{az} = \left[\frac{\pi_{c,2} - \pi_{c,m}}{kT(x^s_1)^2}\,\omega_2\right]_{az} \tag{14}$$

From Eqn. 14 it appears that there will be a maximum if

$$\pi_{c,m} > \pi_{c,1}$$

$$\pi_{c,m} < \pi_{c,2}$$

hence if $\zeta < 0$. In the case of a minimum, one should have $\zeta > 0$. Eqns. 13 and 13′ may be written as:

$$(\pi_{c,m})_{az} = \frac{\pi_{c,1}(x^s_1)^2_{az}\omega_1 - \pi_{c,2}(x^s_2)^2_{az}\omega_2}{(x^s_1)^2_{az}\,\omega_1 - (x^s_2)^2_{az}\,\omega_2} \tag{15}$$

From this relation it is seen that a discontinuity occurs at $(x^s_1)^2{}_{az}\omega_1 = (x^s_2)^2{}_{az}\omega_2$. In the special case when $\omega_1 = \omega_2$, no azeotrope can occur at the mole fraction $x^s_1 = x^s_2 = 0.5$.

The dependence of $(\pi_{c,m})_{az}$ as a function of the mole fraction is given in Fig. 1 for the case of dilauroyl lecithin–cholesterol. Since for this system the surface azeotrope occurs at about 46.2 dynes, the composition of the surface phase at the azeotrope should be: $x^s_1 = 0.75$ and $x^s_{chol} = 0.25$; hence ξ can be calculated according to Eqn. 14.

We are now able to calculate the interaction energy assuming that in the closely packed monolayer, each molecule is surrounded by six neighbors. From Eqn. 2 we deduce: $\alpha = z\Delta\varepsilon$ whereas $\Delta\varepsilon = (\varepsilon_{12} - (\varepsilon_{11} + \varepsilon_{22})/2)$. Eqn. 5′ gives $\xi = \alpha l/kT = \Delta\varepsilon z l/kT$. Hence

$$\Delta\varepsilon = \frac{\xi kT}{zl} = \frac{\xi kT}{6} \tag{16}$$

From the value of the interaction parameter ζ, the interaction energy $\Delta\varepsilon$ can be calculated.

EXPERIMENTAL METHODS

The lecithins, except dipalmitoyl lecithin, were highly purified samples synthesized by Dr. F. C. Reman using methods described previously[20].

Dipalmitoyl lecithin, Grade II, was purchased from Sigma and was used without further purification. Cholesterol was of Analar grade and was obtained from Fluka (spreading experiments using the Goodrich method) and U.C.B. (measurements of collapse pressures). Unbuffered twice distilled water from a pyrex still was used throughout. The pH of this water in equilibrium with laboratory air was about 5.4. Known amounts of previously mixed lipids in $CHCl_3$ or in CCl_4 were delivered on to the surface with an Agla microsyringe, and the solvent was allowed to evaporate for 3 min before compressing the spread film. To ascertain a deviation in the experimental mean molecular area from the theoretical ones the compression curves were measured in the usual way. Measurements of the collapse pressure were performed in a specially constructed apparatus[11]. The barriers of a Langmuir trough coated with paraffin were driven by a synchronic motor, and the surface tension was measured using a Wilhelmy plate and was recorded automatically on a photographic plate.

Since the collapse pressure may be affected by the rate of compression, care was taken that while a given lecithin–cholesterol system was being investigated, the same number of molecules (either cholesterol, lecithin or both) was always spread. In this way, decrease in the molecular area as a function of time was constant throughout the whole series of experiments.

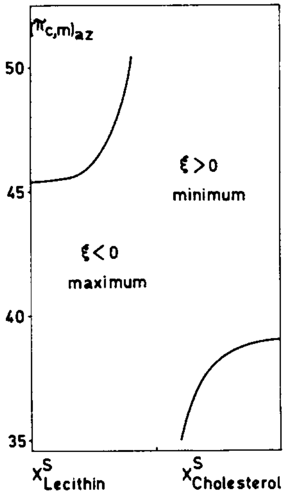

Fig. 1. Relation between the collapse pressure at the azeotrope and the composition of the monolayer for the system dilauroyl lecithin–cholesterol.

We also found that by spreading the components one after another, mixing was not complete as could be seen from the compression diagram and from the two-dimensional phase rule of Defay–Crisp[15]. In order to ascertain the collapse point from the experimental π–A curve, the previously mentioned phase rule was taken into account. All systems reported in this paper showed completely miscible surface mixtures at room temperature (20°).

RESULTS AND DISCUSSION

Interaction between cholesterol and lecithins measured according to the method of De Bernard and Dervichian[7,16] *and* Goodrich[9]

Previous experiments[8,10] revealed no measurable interaction for mixtures of distearoyl lecithin and cholesterol. For dipalmitoyl lecithin, an interaction could be observed only at low surface pressures. Intermediate chain derivatives (such as dimyristoyl lecithin) and mono-unsaturated chain derivatives (such as stearoyl-oleoyl lecithin and dioleoyl lecithin) showed a marked condensation effect. On the other hand, a short chain derivative such as didecanoyl lecithin showed little or no deviation from the simple additivity rule.

These experiments were extended to some other lecithins with short fatty acid constituents. The pressure–area curves of dilauroyl lecithin, diundecyloyl lecithin dinonanoyl lecithin and dioctanoyl lecithin, as well as dimyristoyl lecithin and didecanoyl lecithin (reproduced from ref. 8), are shown in Fig. 2. The pressure–area curves of dimyristoyl lecithin, dilauroyl lecithin and diundecyloyl lecithin show great similarity. However, didecanoyl lecithin and dinonanoyl lecithin show a shift to higher areas per molecule. Dioctanoyl lecithin forms already less stable monolayers as is demonstrated by the low collapse pressure. The dipalmitoyl lecithin used in this experiment showed a transition point at a surface pressure of 52 dynes/cm and an area of 37 Å^2.

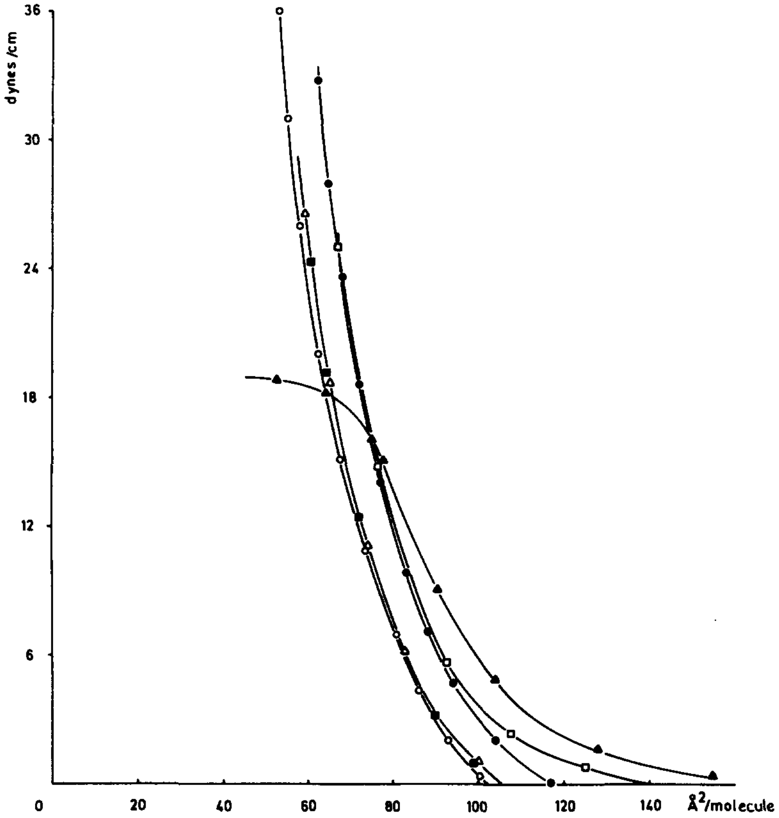

Fig. 2. Compression diagram of ○, dimyristoyl lecithin (diC14:0 PC); ■, dilauroyl lecithin (diC12:0 PC); △, diundecyloyl lecithin (diC11:0 PC); ●, didecanoyl lecithin (diC10:0 PC); □, dinonanoyl lecithin (diC9:0 PC); and ▲, dioctanoyl lecithin (diC8:0 PC).

Pure samples showed transition points at lower surface pressures and higher areas per molecule[10,18]. The dimyristoyl curve varied from the first one measured by Cadenhead *et al.*[17] but in a later publication[18] they showed a curve similar to that previously obtained by us. The shift of didecanoyl lecithin to higher areas is in contrast with the present data of Phillips and Chapman[18].

The mean molecular areas of mixed monolayers of cholesterol with dilauroyl lecithin, diundecyloyl lecithin, didecanoyl lecithin and dinonanoyl lecithin as a function of the composition at different surface pressures are given in Fig. 3.

No interaction is observed in the case of dinonanoyl lecithin; also dioctanoyl lecithin showed ideal behavior. For didecanoyl lecithin, no detectable interaction was observed at rather low surface pressures as previously reported. However, at high surface pressures of 24 dynes/cm, a small decrease in the area of maximally 2–3 Å^2 per molecule could be detected.

The molecular areas of diundecyloyl lecithin and of dilauroyl lecithin were strongly reduced by the presence of cholesterol.

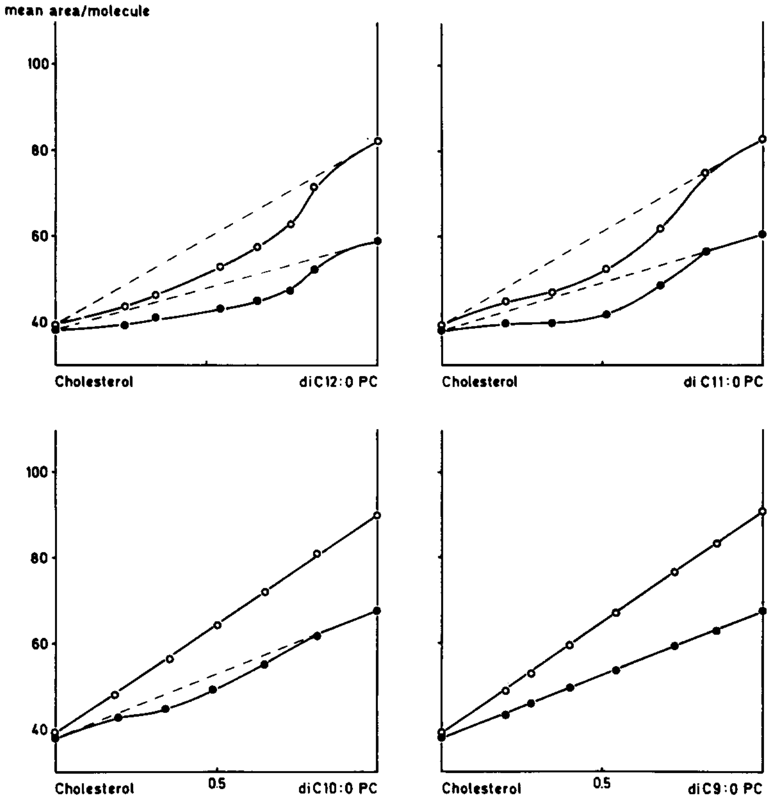

Fig. 3. Mean molecular area as a function of the composition for dilauroyl lecithin (diC12:0 PC), diundecyloyl lecithin (diC11:0 PC), didecanoyl lecithin (diC10:0 PC) and dinonanoyl lecithin (diC9:0 PC) with cholesterol at a surface pressure of 6 dynes/cm (○) and 24 dynes/cm (●), using the Goodrich method.

Collapse pressure of mixed monolayers of lecithins with cholesterol

The collapse pressures and the molecular areas of the tested compounds are given in Table I. The collapse pressure of cholesterol was not completely constant in the various experiments. The compression rate was kept constant for all cholesterol–lecithin mixtures. The collapse pressure of dipalmitoyl lecithin was found to be rather high, even higher than for distearoyl lecithin. CADENHEAD AND PHILLIPS[19] also reported a value of 63 dynes/cm. However, since the dipalmitoyl lecithin used in this experiment was not as pure as our other lecithins, no further attention was paid to this phenomenon.

With the aid of the parameters, summarized in Table I, the collapse pressure of the mixed film can be calculated according to Eqn. 1 or 1′ and compared with the experimental points. The lecithins form completely miscible monolayers as can be derived from the π–A plots, considering the two dimensional phase rule of Defay–Crisp[15]. As is demonstrated in Fig. 4, no interaction is observed between distearoyl

TABLE I

COLLAPSE PRESSURE, π_c, AND CROSS SECTIONAL AREA, ω, OF DIFFERENT LECITHINS AND CHOLESTEROL

Lipid	π_c	ω (Å^2)
Distearoyl lecithin	58.0	35
Dipalmitoyl lecithin	63.0	35
Dimyristoyl lecithin	48.6	35
Dilauroyl lecithin	45.4	36
Diundecyloyl lecithin	44.0	36
Didecanoyl lecithin	43.8	38
Dinonanoyl lecithin	42.7	38
Oleoyl-stearoyl lecithin	44.4	54
Dioleoyl lecithin	41.6	53
Dilinoleoyl lecithin	39.3	53
Cholesterol	39.4–40.9	35–36

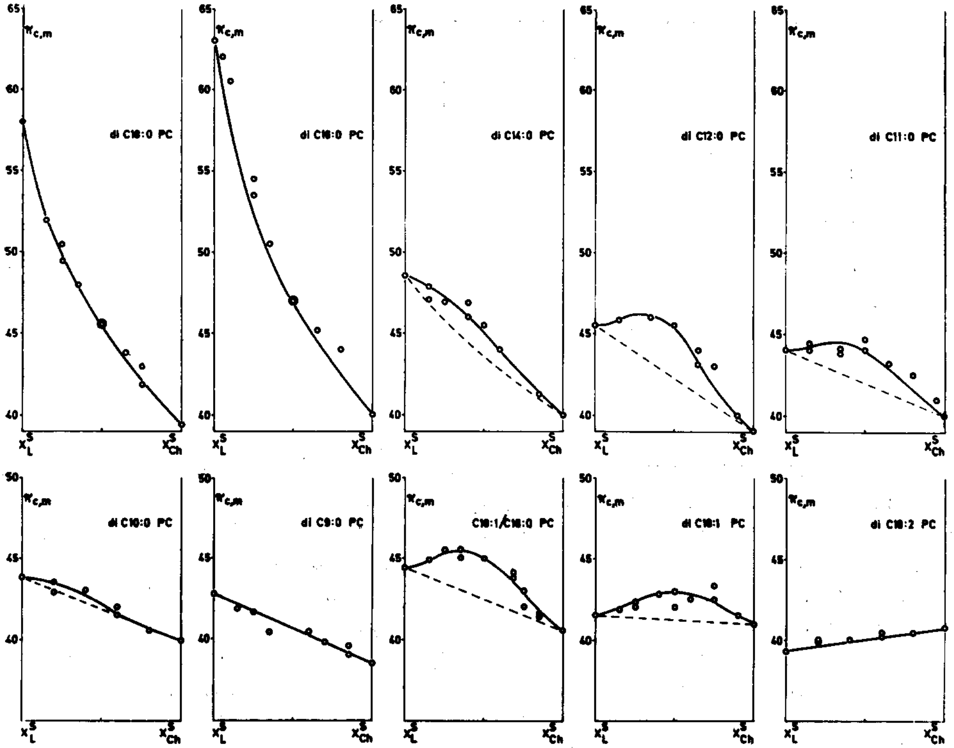

Fig. 4. Collapse pressure $\pi_{c,m}$ as a function of the surface composition of mixed monolayers of cholesterol with distearoyl lecithin (diC18:0 PC), dipalmitoyl lecithin (diC16:0 PC), dimyristoyl lecithin (diC14:0 PC), dilauroyl lecithin (diC12:0 PC), diundecyloyl lecithin (diC11:0 PC), didecanoyl lecithin (diC10:0 PC), dinonanoyl lecithin (diC9:0 PC), oleoyl-stearoyl lecithin (C18:1/C18:0 PC), dioleoyl lecithin (diC18:1 PC) and dilinoleoyl lecithin (diC18:2 PC). Full lines calculated according to Eqn. 7 dotted lines according to Eqn. 1′.

lecithin, dipalmitoyl lecithin, dinonanoyl lecithin or dilinoleoyl lecithin and cholesterol. The other lecithins, notably dimyristoyl lecithin, dilauroyl lecithin, diundecyloyl lecithin, oleoyl-stearoyl lecithin and dioleoyl lecithin, revealed an appreciable deviation from the ideal behavior. Didecanoyl lecithin showed a barely detectable interaction. Assuming a hexagonal lattice for this cholesterol–phospholipid surface mixture, the interaction parameter was calculated from this deviation. It can be observed that the curves calculated, with the aid of a suitable value for the interaction parameter, reasonably substantiate the experimental points.

This supports our assumption that in these cases the surface mixtures behave as a regular solution. In view of the scattering of the experimental points and the mathematical complexity of our equations, this interaction parameter is only a good estimate. Knowing the interaction parameter ξ from Eqn. 16, the interaction $\Delta\varepsilon$ can be calculated. The results are given in Table II.

TABLE II

INTERACTION PARAMETER, ξ, MOLE FRACTION OF LECITHIN AT THE AZEOTROPE, x_1^s, AND INTERACTION ENERGIES $\Delta\varepsilon$

Lecithin	ξ	x_1^s	$\Delta\varepsilon$ ($zl = 6$) (*cal/mol*)*
Distearoyl	0	—	0
Dipalmitoyl	0	—	0
Dimyristoyl	−0.50	—	50
Dilauroyl	−1.14	0.75	114
Diundecyloyl	−0.71	0.75	71
Didecanoyl	−0.2	—	20
Dinonanoyl	0	—	0
Oleoyl-stearoyl	−1.12	0.65	112
Dioleoyl	−0.78	0.50	78
Dilinoleoyl	0	—	0

* $\Delta\varepsilon = (RT/6)\ \xi$.

CONCLUSIONS

A complete agreement is found between the results obtained using the Goodrich method and the one measuring the collapse pressure. From the data in Table II, two interesting conclusions can be drawn. Initially the interaction starts from zero with phospholipids containing short chain fatty acids (dinonanoyl lecithin) and increases with increasing chain length (didecanoyl lecithin and diundecyloyl lecithin). The interaction parameter is maximal for dilauroyl lecithin. A further increase in the chain length reduces the interaction (dimyristoyl lecithin), and it becomes zero for dipalmitoyl lecithin and distearoyl lecithin. Secondly, unsaturation in the paraffin chain of the fatty acids shows a marked effect. The interaction parameter is zero for distearoyl lecithin, but a high value is found for oleoyl-stearoyl lecithin, containing one mono-unsaturated fatty acid constituent. Interaction is reduced for dioleoyl lecithin, containing two mono-unsaturated fatty acid constituents; whereas for dilinoleoyl lecithin, containing two di-unsaturated fatty acid constituents, the calculated interaction parameter is found to be zero. These findings are in agreement with previous observations that phosphoglycerides containing polyunsaturated fatty acids show no condensation effect with cholesterol[8].

In the last column of Table II, the interaction energies are summarized. It should be emphasized that the calculation is based on a hexagonal surface lattice. Although this assumption seems reasonable, it still remains an assumption. If more experimental evidence can be found for this assumption, it should be possible to describe the interaction between phospholipids and cholesterol with the aid of a useful Lennard–Jones potential model.

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