

On the Kinetics of Growth of Single Clusters and Ostwald  
Ripening Under the Influence of Electric Fields

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## 1. Introduction

The investigation of the kinetics of first-order phase transitions remains despite its long history an actively developing field of research (see, e.g., [1-5]). This is due, on one hand, to the complexity of this phenomenon and, on the other hand, to the widespread technological applications.

One of the problems, which are of importance for an understanding of the course of the transition, consists in the description of the growth of single clusters and ensembles of clusters denoted as Ostwald ripening [6-8]. These processes can be accompanied and influenced by external or evolving in the course of the transition elastic, electric or other fields. Thus an, as far as possible, general method of theoretical description of cluster growth and Ostwald ripening under the influence of different fields is of theoretical and practical interest.

In recent years the influence of elastic fields on cluster growth and Ostwald ripening in application to segregation processes in glass-

forming melts was intensively studied by one of the authors in cooperation with I. Gutzow and R. Pascova (Sofia) [9-12]. In this analysis, two different methods have been quantitatively equivalent.

One theoretical approach is based on the steady-state solution of the diffusion equation (see, e.g., [10] and also [12c]), while the second of the applied methods interconnects the growth rate of single or ensembles of clusters with the resulting change in the thermodynamic potential of the whole system consisting of  $s$  clusters growing or dissolving in the ambient phase (see, e.g., [5;12a,b]). A comparison of both methods may be found in [12c].

In the present communication the second of the mentioned methods is applied to the growth of ensembles of clusters condensing on ions in a binary solid or liquid solution for constant values of the pressure  $p$  and temperature  $T$ . Both the growth of singles clusters and Ostwald ripening is discussed where, in extension of the theory developed earlier, the possibility of direct interactions between the clusters is taken into account.

The general character of the outlined approach gives the possibility to discuss also the influence of other possible types of electric fields on cluster growth by the same method as will be shown in a forthcoming paper, dealing with the kinetics of formation of thermodynamically stabilized colloidal dispersions [13].

## 2. Condensation on Ions in Binary Solid or Liquid Solutions: Thermodynamic Aspects

For simplicity of the notations we consider here the case, that the clusters are formed by one component only. Generalizations can be carried out without principal difficulties [5].

The change of the characteristic thermodynamic potential of the initially homogeneous metastable system connected with the formation of  $s$  clusters of the new phase all, in general of different sizes, can be written then as

$$G = \sum_{j=1}^s \left\{ n_{\alpha}^{(j)} \left[ \mu_{2\beta}(x') - \mu_{2\beta}(x_{\beta}) \right] + \sigma^{(j)} A^{(j)} \right\} + \sum_{i=1}^2 \left[ \mu_{i\beta}(x_{\beta}) - \mu_{i\beta}(x) \right] n_i + \phi_{tot}^{(\epsilon)} \quad (2.1)$$

$n_{\alpha}$  is the number of particles in the cluster,  $\mu_{i\beta}$  is the chemical potential of the solute (2) and the solvent (1) in the ambient phase,  $n_i$  are the total number of particles of the components, respectively,  $\sigma$  is the specific surface energy and  $A$  the surface area of a cluster. The different clusters are specified by the superscript  $j=1,2,\dots,s$ .  $x$  is the molar fraction of the solute in the homogeneous initial state,  $x'$  is the corresponding equilibrium value for a coexistence of both phases at a planar interface and  $x_{\beta}$  is the variable molar fraction in the course of the transition.

Electric interactions are expressed in eq.(2.1) via changes of the energy of the electric field  $\phi_{tot}^{(\epsilon)}$ , resulting from the formation of the



s clusters. In general,  $\phi^{(\epsilon)}$  depends on the position, the size and the specific properties of all clusters.

For the case of s clusters of the same size, carrying an identical charge, eq.(2.1) can be simplified to

$$G = sn_{\alpha} \left[ \mu_{2\beta}(x') - \mu_{2\beta}(x_{\beta}) \right] + s\sigma A + \sum_{i=1}^2 \left[ \mu_{i\beta}(x_{\beta}) - \mu_{i\beta}(x) \right] n_i + s \cdot \phi^{(\epsilon)}(s, V_{\alpha}) \quad (2.2)$$

In this picture, the influence of direct electric interactions between the clusters is expressed via the dependence of  $\phi^{(\epsilon)}$  on s. For a sufficiently low density of ions in the system, these direct interactions are negligible and  $\phi^{(\epsilon)}$  is a function only of the volume  $V_{\alpha}$  of the clusters.

The thermodynamic equilibrium states - assuming the number of clusters is fixed - can be obtained from eq.(2.2) by a derivation of  $\Delta G$  with respect to the radius of the cluster R.

$$\left[ \frac{\partial \Delta G}{\partial R} \right]_s = -4\pi R^2 c_{\alpha} s \left\{ \mu_{2\beta}(x_{\beta}) - \mu_{2\beta}(x') - \frac{2\sigma}{c_{\alpha} R} - \frac{1}{c_{\alpha}} \frac{\partial \phi^{(\epsilon)}}{\partial V_{\alpha}} \right\} = 0 \quad (2.3)$$

(It can be shown, that equilibrium states are possible only, if all clusters are of the same size [5]. Thus, we may start immediately with eq.(2.2).)

Further information on the equilibrium states, determined by eq.(2.4), can be obtained from the second derivative

$$\left[ \frac{\partial^2 \Delta G}{\partial R^2} \right]_S = - 8\pi\sigma s \left\{ 1 + Z - \frac{R^2}{2\sigma} \frac{\partial^2 \phi(\epsilon)}{\partial R \partial V_\alpha} \right\} \quad (2.4)$$

where Z is given by

$$Z = - \frac{3c_\alpha R}{2\sigma} \frac{\text{sn}_\alpha n_1}{(n_1 + n_2 - \text{sn}_\alpha)^2} \frac{\partial \mu_{2\beta}}{\partial x_\beta} \quad (2.5)$$

Since from the general thermodynamic stability conditions  $\partial \mu_{2\beta} / \partial x_\beta > 0$  we obtain

$$Z < 0 \quad (2.6)$$

Moreover, for the maximum of  $\Delta G(R=R_c)$  it follows

$$1 + Z - \frac{R^2}{2\sigma} \frac{\partial^2 \phi(\epsilon)}{\partial R \partial V_\alpha} > 0 \quad R=R_c \quad (2.7)$$

while for the minima

$$1 + Z - \frac{R^2}{2\sigma} \frac{\partial^2 \phi(\epsilon)}{\partial R \partial V_\alpha} < 0 \quad R=R_{st} \quad (2.8)$$

holds.

Eq.(2.3) can be considered as a relation connecting the actual values of  $R_c$  and  $R_{st}$  with the number of clusters  $s$  in the system. Taking this fact into account by a derivation of eq.(2.3) with respect to  $s$  we obtain

$$\frac{dR}{ds} = -\frac{R}{3s} \frac{2 - \frac{3Rs}{2\sigma} \frac{\partial^2 \phi(\epsilon)}{\partial s \partial V_\alpha}}{1 + 2 - \frac{R^2}{2\sigma} \frac{\partial^2 \phi(\epsilon)}{\partial R \partial V_\alpha}} \quad (2.9)$$

The corresponding variations of the values of  $\Delta G$  for the extrema are determined by

$$\frac{d\Delta G}{ds} = \frac{1}{3} \sigma A + \phi(\epsilon) - V_\alpha \frac{\partial \phi(\epsilon)}{\partial V_\alpha} + s \frac{\partial \phi(\epsilon)}{\partial s} \quad (2.10)$$

It has to be remembered that eq.(2.3) determines only necessary thermodynamic equilibrium conditions, since in addition to a variation of the radius also a variation of the number of clusters is possible.

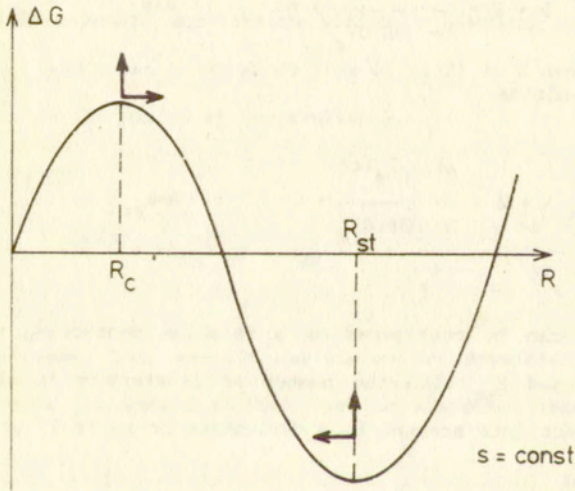


Fig. 1.

Qualitative behaviour of the function  $\Delta G = \Delta G(R, s = \text{const})$  in dependence on the radius. By arrows the variation of the position of the extrema with an increasing number of clusters  $s$  is indicated.



In the limiting case  $\phi^{(\epsilon)} = 0$  the curves  $\Delta G = \Delta G(R, s)$  show a behaviour, as presented in Fig.1. By arrows the variation of the position of the extrema with an increasing number of clusters is indicated.

Vice versa, a decrease of the number of clusters is connected with a decrease of the Gibbs free energy. Consequently, in the considered limiting case, the thermodynamic equilibrium state, the system tends to in the course of the evolution, corresponds to a heterogeneous system consisting of one cluster in the otherwise homogeneous medium.

To account for the influence of electric fields on growth the term  $\phi_{\text{tot}}^{(\epsilon)}$  or  $\phi^{(\epsilon)}(s, V_\alpha)$  has to be known. The calculation of the corresponding expression for one particular model - condensation on ions - is carried out in the next chapter.

### 3. Condensation on Ions: Contribution of the Energy of the Electric Field

Denoting by  $\epsilon_M = \epsilon_o \epsilon_{Mr}$  and  $\epsilon_t = \epsilon_c \epsilon_{tr}$  the dielectric constants of the ambient and cluster phases, respectively, the electrostatic field energy before (eqs.(3.1) and (3.2)) and after the formation of a cluster with the radius  $R$  (eqs.3.3) and (3.4)) condensing on one ion with the charge  $q$  and radius  $R_a$  is given by

$$U = U_q + \frac{1}{2} \int_{R_a}^{\infty} \bar{E} \bar{D} dV \quad (3.1)$$

$$U = U_q + \frac{q^2}{8\pi\epsilon_M} \frac{1}{R_a} \quad (3.2)$$

and

$$U = U_q + \frac{1}{2} \int_{R_a}^R \bar{E} \bar{D} dV + \frac{1}{2} \int_R^{\infty} \bar{E} \bar{D} dV \quad (3.3)$$

$$U = U_q + \frac{q^2}{8\pi\epsilon_t} \left[ \frac{1}{R_a} - \frac{1}{R} \right] + \frac{q^2}{8\pi\epsilon_M} \frac{1}{R} \quad (3.4)$$

$U_q$  is the electric self energy of the ion.

The change of the energy of the electric field due to the formation of one cluster is obtained, consequently, as

$$\phi^{(\epsilon)} = \frac{q^2}{8\pi} \left[ \frac{1}{R_a} - \frac{1}{R} \right] \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \quad s=1 \quad (3.5)$$

Two cases may be distinguished. If  $\epsilon_t > \epsilon_M$  (e.g., liquid cluster in the vapor, metallic cluster in an amorphous matrix)  $\phi^{(\epsilon)}$  gives a negative contribution to  $\Delta G$ . In this case, instead of the qualitative behaviour of the function  $\Delta G = \Delta G(R)$  as presented in Fig.1, we may either obtain an additional minimum for small cluster sizes or the maximum vanishes et al. (see Fig.2a,b).



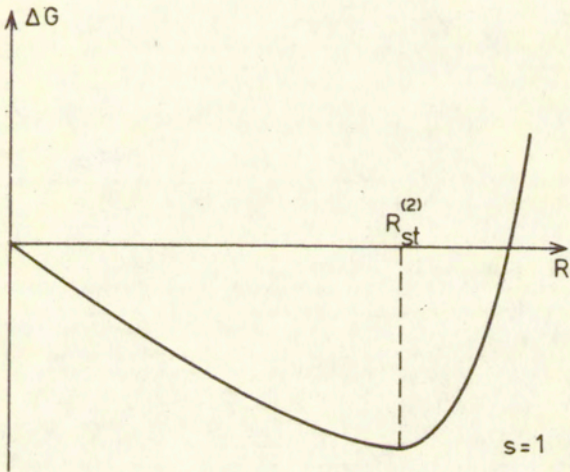
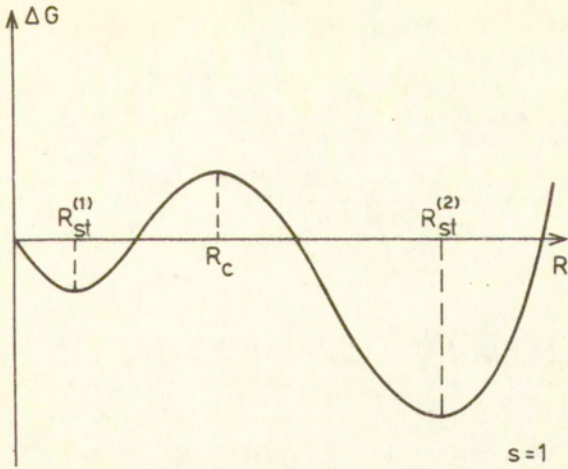


Fig. 2.

Influence of electrostatic polarization effects on  $\Delta G = \Delta G(R)$  for  $s=1$  (compare Fig. 1). Either an additional minimum for  $R=R_{st}$  is found or the first extremum vanishes.

The alternative situation  $\epsilon_t < \epsilon_M$  results only in slight quantitative modifications of the curve shown in Fig.1, especially for small values of R.

A substitution of  $\phi^{(\epsilon)}$  (eq. (3.5)) into eq. (2.3) yields

$$\mu_{2\beta}(x') - \mu_{2\beta}(x') - \frac{2\sigma}{c_\alpha R} - \frac{1}{2c_\alpha} \left[ \frac{q}{4\pi R^2} \right]^2 \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] = 0 \quad (3.6)$$

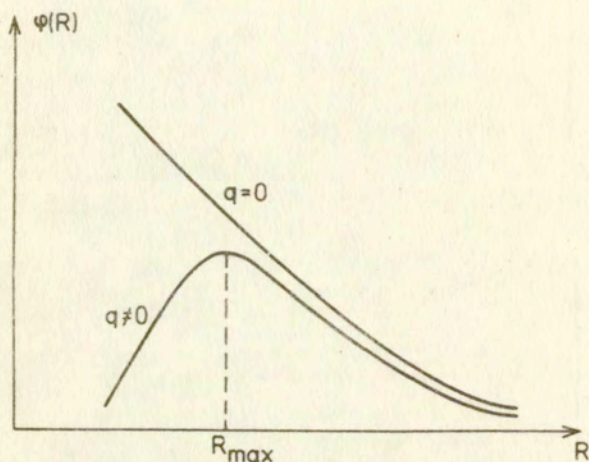


Fig.3.

The r.h.s. of eq. (3.7) as a function of R. For comparison the corresponding curve for  $q=0$  is also given.

Expressing the chemical potential via the perfect solution law we get further

$$\ln \frac{c_\beta}{c'} = \frac{1}{c_\alpha kT} \left[ \frac{2\sigma}{R} + \frac{1}{2} \left[ \frac{q}{4\pi R^2} \right]^2 \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \right] \equiv \phi(R) \quad (3.7)$$

which corresponds to the well-known Thomson equation for a condensation of a one-component gas on ions [14]. It is applied widely to a large number of different physical systems (e.g.[15-18]), though modifications and generalizations are, of course, possible [19,20].

The r.h.s. of eq.(3.7) ( $\varphi(R)$ ) is shown as a function of  $R$  in Fig.3.

In agreement with Figs.2 for fixed values of  $c_\beta$  and small values of  $R$  either two ( $\ln - c_\beta/c' < \varphi(R_{\max})$ ) or no solutions ( $\ln c_\beta/c' > \varphi(R_{\max})$ ) of the necessary equilibrium conditions (3.6) exist.

If more than one charged cluster is formed in the system, then the electrostatic energy can be calculated starting with

$$U = \frac{1}{2} \int \bar{E} \bar{D} \, dV \quad (3.8)$$

$$\bar{E} = \sum_{i=1}^s \bar{E}_i \quad \bar{D} = \sum_{j=1}^s \bar{D}_j \quad (3.9)$$

Here and in the following, constant self energy contributions are omitted, since they have no effect on  $\phi^{(\epsilon)}$ . A substitution of eq.(3.9) into (3.8) yields

$$U = \frac{1}{2} \sum_{i=1}^s \sum_{j=1}^s \int \bar{E}_i \bar{D}_j \, dV \quad (3.10)$$

or

$$U = \frac{1}{2} \sum_{i=1}^s \int \frac{\bar{D}_i^2}{\epsilon} \, dV + \sum_{i < j} \int \frac{\bar{D}_i \bar{D}_j}{\epsilon} \, dV \quad (3.11)$$

where the different regions of space the appropriate value of  $\epsilon$  has to



be substituted into eq.(3.11).

Denoting the radii of the different clusters by  $R_i$ , the first term gives the contribution  $\phi_1^{(\epsilon)}$  to  $\phi_{tot}^{(\epsilon)}$

$$\phi_1^{(\epsilon)} = \sum_{i=1}^s \frac{q^2}{8\pi} \left[ \frac{1}{R_a} - \frac{1}{R_i} \right] \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \quad (3.12)$$

with

$$\bar{D}_i = \frac{q}{4\pi} \frac{\bar{r}_{ij} + \bar{r}}{|\bar{r}_{ij} + \bar{r}|^3} \quad \bar{r}_{ij} = \bar{r}_j - \bar{r}_i \quad (3.13)$$

the second term in eq.(3.11) results in  $\phi_2^{(\epsilon)}$  given by

$$\phi_2^{(\epsilon)} = \left[ \frac{q}{4\pi} \right]^2 \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \sum_{i < j} \int_{V(j)} \frac{(\bar{r}_{ij} + \bar{r}) \bar{r}}{|\bar{r}_{ij} + \bar{r}|^3 \bar{r}^3} dV \quad (3.14)$$

The integral has to be calculated over the volume of cluster  $j$  in the interval  $(R_a, R_j)$ .  $r=0$  corresponds to the centre of the  $j$ -th cluster.

The distance between the clusters is assumed in the following to be large compared with their size ( $|\bar{r}_{ij}| \gg \bar{r}$ ), consequently, we get

$$\phi_2^{(\epsilon)} \cong \left[ \frac{q}{4\pi} \right]^2 \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \sum_{i < j} \left\{ \int_{V(j)} \frac{\bar{r}_{ij} \bar{r}}{r_{ij}^3 \bar{r}^3} dV + \int_{V(j)} \frac{dV}{r_{ij}^3 \bar{r}} \right\} \quad (3.15)$$

and

$$\phi_2^{(\epsilon)} \cong \frac{q^2}{8\pi} \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \sum_{i=1}^{j-1} \sum_{j=2}^s (R_j^2 - R_a^2) / r_{ij}^3 \quad (3.16)$$

In general, we may write

$$\phi_{\text{tot}}^{(\epsilon)} = \phi_1^{(\epsilon)} + \phi_2^{(\epsilon)} \quad (3.17)$$

and for a system of  $s$  identical clusters

$$\phi_{\text{tot}}^{(\epsilon)} \cong s \frac{q^2}{8\pi} \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \left[ \frac{1}{R_a} - \frac{1}{R} + \frac{(R^2 - R_a^2)}{s} \sum_{i < j}^s \frac{1}{r_{ij}^3} \right] \quad (3.18)$$

consequently,

$$\phi^{(\epsilon)}(s; R) \cong \frac{q^2}{8\pi} \left[ \frac{1}{\epsilon_t} - \frac{1}{\epsilon_M} \right] \left[ \frac{1}{R_a} - \frac{1}{R} + \frac{(R^2 - R_a^2)}{s} \sum_{i < j}^s \frac{1}{r_{ij}^3} \right] \quad (3.19)$$

is the approximate expression for  $\phi^{(\epsilon)}$ .

The term  $\sum_{i < j}^s (1/r_{ij}^3)$  depends on the number and distribution of clusters in the system. If the clusters are distributed chaotically the average dependence of the value of this term on the number of clusters can be calculated by averaging over a large number of random distribu-

tions. For large values of  $s$  they can be approximated by an equation of the form

$$\sum_{i < j}^s \frac{1}{r_{ij}^3} = A s^2 \quad (3.20)$$

#### 4. Kinetics of Growth of Single Clusters

Based on the diffusion equation, written, e.g., in the form

$$\bar{j} = - \frac{Dc}{kT} \text{grad } \mu \quad (4.1)$$

in preceding papers a general growth equation for clusters of a newly formed phase was developed, replacing in eq. (4.1)  $\text{grad } \mu$  as the thermodynamic driving force of cluster growth via

$$\text{grad } \mu \Rightarrow \frac{\Delta\mu}{1} \Rightarrow - \frac{1}{1} \frac{\partial\phi}{\partial n_\alpha} \quad (4.2)$$



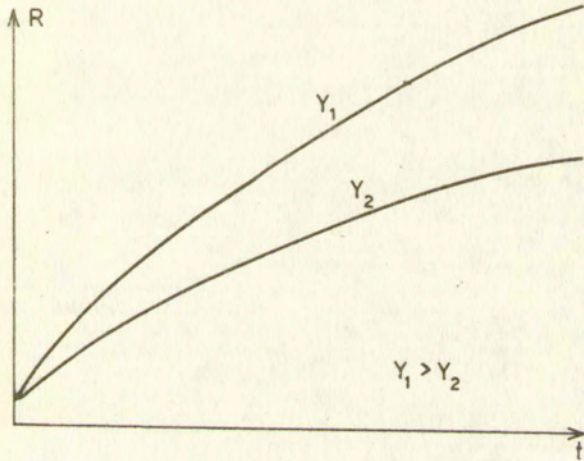
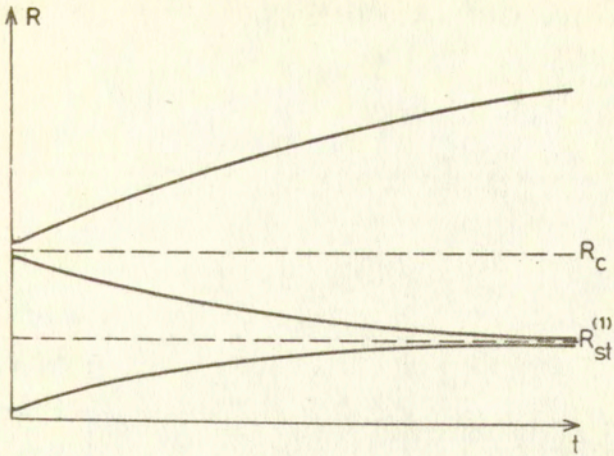


Fig. 4.  
Development of the radius  $R$  vs. the time  $t$  for different initial values (a) and different initial supersaturations (b)

This results in the following expression for the variation of the number of particles  $n_\alpha$  in a cluster [5,21]

$$\frac{dn_\alpha}{dt} = - \frac{Dc}{c_\alpha kT} \frac{1}{l} \frac{\partial \phi}{\partial R} \quad (4.3)$$

$l$  is the width of the inhomogeneous region between cluster and surrounding homogeneous matrix ( $l = \text{const.}$  for kinetic limited growth,  $l=R$  for diffusion-limited growth) [5],  $D$  is the diffusion coefficient,  $c$  the concentration of segregating particles in the homogeneous part of the matrix,  $k$  is the Boltzmann constant and  $\phi$  the characteristic thermodynamic potential, in our case the Gibbs free energy, of the heterogeneous system-cluster growing in the ambient phase.

A substitution of eqs.(2.3) with (3.5) into eq.(4.3) yields ( $s=1$ ,  $l=R$ )

$$\frac{dR}{dt} = \frac{Dc}{c_\alpha kT} \frac{1}{R} \left\{ \mu_{2\beta}(x_\beta) - \mu_{2\beta}(x') - \frac{2\sigma}{c_\alpha R} - \frac{1}{2} \left[ \frac{q}{4\pi} \right]^2 \left[ \frac{1}{c_t} - \frac{1}{c_M} \right] \frac{1}{R^4} \right\} \quad (4.4)$$

Solutions of eq.(4.4) for different initial values and initial supersaturations are shown in Figs.4.

### 5. Kinetics of Ostwald Ripening

Replacing in eq.(4.3) the thermodynamic driving force of cluster growth by the decrease of  $\phi$  due to the decrease of the number of clusters

$$\frac{\partial \phi}{\partial R} \Rightarrow \frac{\partial \phi}{\partial s} \frac{ds}{dR} \quad (5.1)$$

and applying the thermodynamic relationships developed in chapter 3 the following set of equations is obtained for the description of the time evolution of the number of clusters  $a$  and their average size  $R$  in the course of Ostwald ripening [5,11,12a,b]

$$\frac{dR}{dt} = \frac{8}{27} \frac{Dc_{\beta}}{c_{\alpha}^2 kT} \frac{1}{1R} \left\{ \sigma + \frac{3}{4\pi R^2} \left[ \phi^{(\epsilon)} - v_{\alpha} \frac{\partial \phi^{(\epsilon)}}{\partial v_{\alpha}} + s \frac{\partial \phi^{(\epsilon)}}{\partial s} \right] \right\}.$$

$$1 + Z - \frac{R^2}{2\sigma} \frac{\partial^2 \phi^{(\epsilon)}}{\partial R \partial v_{\alpha}} \quad (5.2)$$

$$Z \left[ 1 - \frac{3R^2 s}{2\sigma Z} \frac{\partial^2 \phi^{(\epsilon)}}{\partial s \partial v_{\alpha}} \right]$$



$$\frac{d}{dt} [\ln(s)] = - \frac{1}{Z} \frac{d}{dt} [\ln(R^3)] \frac{1 + Z - \frac{R^2}{2\sigma} \frac{\partial^2 \phi(\epsilon)}{\partial R \partial V_\alpha}}{1 - \frac{3Rs}{2\sigma Z} \frac{\partial^2 \phi(\epsilon)}{\partial s \partial V_\alpha}} \quad (5.3)$$

If direct elastic interactions  $((\partial\phi^{(\epsilon)}/\partial s) = 0)$  are neglected eqs.(2.10) or (5.2) lead to the conclusion, that with an increasing cluster size electric field effects become unimportant for the evolution of the ensemble of clusters. This conclusion remains valid also for the case, that direct interactions between the clusters according to eqs. (3.19) and (3.20) are taken into account.

## 6. Discussion

In the present paper a theory of cluster growth and Ostwald ripening under the influence of electric fields was developed. The general theory was applied to the case, that the electric interactions can be reflected by a contribution, derived for a single cluster already by J.J.Thomson [14].

However, due to the general character of the outlined theory a generalization to other models of electric field contribution to cluster growth and Ostwald ripening is straightforward. One of such possible extensions consists in the application to the process of formation of thermodynamically stabilized colloidal dispersions [22-

28]. Such an extension will be presented in a forthcoming contribution [13].

It is to be mentioned, however, that the general applicability of the outlined method is connected with two simplifying approximations. The first approximation consists in the assumption, underlying the derivation of eqs.(4.3) and (5.2), that the diffusion coefficient of the segregating particles is not changed by the fields. In general, this assumption does not lead to significant quantitative deviations in the growth laws, qualitative changes do not occur. Moreover, this approximation can be omitted (see [12c]), if necessary.

The second of the mentioned approximations is connected with the calculation of the thermodynamic driving force of cluster growth in the stage of Ostwald ripening based on the consideration of an idealized ensemble of  $s$  identical clusters and the identification of the common size of the clusters in the idealized ensemble with the average cluster size in the real ensemble. This approximation is shown not to change qualitatively the behaviour in comparison with predictions of exact theories developed for special cases. Small quantitative deviations may be compensated by the introduction of an correction factor, which is of the order  $1/3$  (see, e.g., [5,12a,b]).

## References

1. A.C.Zettlemoyer (ed.), "Nucleation". Elsevier, New York, 1969; Adv.Colloid Interface Sci. 7, (1977)

2. J.D.Gunton, M.San Miguel and P.S.Sahni, [in:] "Phase Transitions and Critical Phenomena" (C.Domb, M.S.Green and J.L.Lebowitz, Eds.) vol.8, London-New York, 1983
3. A.W.Hodgson, Adv.Colloid Interface Sci., 21, 303, (1984)
4. K.Binder and D.Stauffer, Adv.Physics 25, 343, (1976)
5. H.Ulbricht, J.Schmelzer, R.Mahnke and F.Schweitzer, "Thermodynamics of Finite Systems and the Kinetics of First-Order Phase Transitions", Teubner, Leipzig, 1988
6. I.M.Lifshitz and V.V.Slyozov
  - a) J.Exper.Theor.Phys. (USSR) 35, 479, (1958);
  - b) Solid State Physics (USSR) 1, 1401, (1959);
  - c) J.Phys.Chem.Solids, 19, 35, (1961)
7. P.W.Voorhees, J.Stat.Phys. 38, 231, (1985)
8. M.Marder, Phys.Rev. A36, 858, (1987)
9. R.Pascova, I.Gutzow, J.Schmelzer and I.Tomov, A Model Investigation of the Process of Phase Formation in Photochromic Glasses, J.Material Science, in press
10. J.Schmelzer, I.Gutzow and R.Pascova, Kinetics of Segregation in Elastic and Viscoelastic Media, J.Crystal Growth, subm. for publication
11. J.Schmelzer, R.Pascova, I.Gutzow, Cluster Growth and Ostwald Ripening in Viscoelastic Media, Physica status solidi
12. J.Schmelzer and I.Gutzow
  - a) Wiss.Zeitschrift der Wilhelm-Pieck-Universität Rostock 35, Helt 4, 5, (1986)



- b) Z.Phys.Chemie (Leipzig) 269, 253, (1988)
- c) On the Influence of Ellastic Strains on Cluster Growth,  
Rostocker Physikalische Manuskripte 13, 82, (1989)
13. J.Schmelzer H.Tietze, On the Kinetics of Formation of Thermodynamically Stabilized Colloidal Dispersions, in preparation
14. J.J.Thomson, "Conduction of Electricity Through Gases", 2nd edition, Cambridge Univ.Press, p.179 ff, (1906)
15. M.Volmer, "Kinetik der Phasenbildung", Dresden, 1939
16. K.C.Russell, J.Chem.Phys. 50, 1809, (1969)
17. A.W.Castleman and I.N.Tang, J.Chem.Phys. 57, 3629, (1972)
18. D.Stachorska, J.Chem.Phys. 42, 1887, (1965)
19. A.I.Rusanov and F.M.Kuni, J.Colloid Interface Sci. 100, 264, (1984)
20. S.H.Suck, J.Chem.Phys. 79, 5090, (1981)
21. J.Schmelzer, Z.Phys.Chemie (Leipzig) 266, 1057, (1985)
22. H.Sonntag, "Lehrbuch der Kolloidwissenschaft", VEB Deutscher Verlag der Wissenschaften, Berlin, 1977
23. L.Marszall, Colloids and Surfaces 25, 279, (1987)
24. P.Strehlow, J.Non-Crystalline Solids 107, 55, (1988)
25. A.S.Kabalnov, A.V.Pertzov, E.D.Shchukin, J.Colloid Interface Sci. 118, 590, (1987)

26. J. Sonnefeld, W. Vogelsberger and G. Rudakoff, Z. Phys. Chemie (Leipzig) 266, 449, (1985)
27. J.-M. Victor, J.-P. Hansen, J. Chem. Soc., Faraday Trans. 2, 81, 43, (1985)
28. K. Quitzsch, "Thermodynamic Problems of Micelle Formation", Invited Lecture, 6th International Conference mixtures of Non-Electrolytes and Intermolecular Interactions, Merseburg, August 23-25, 1988, GDR