A maxium entropy ansatz for nonlinear response theory

Dyre, J. C.

Publication date:
1989

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Dyre, J. C. (1989). *A maxium entropy ansatz for nonlinear response theory*. Roskilde Universitet.

TEKST NR 176   1989

A MAXIMUM ENTROPY ANSATZ FOR NONLINEAR RESPONSE THEORY

By: Jeppe C. Dyre

TEKSTER fra

Abstract:

An approximate nonlinear response theory is derived by
maximizing the information theoretic entropy in the space
of fluctuations $J(t)$ of the degree of freedom of interest,
subject to constant energy dissipation in the external
field. The resulting formalism expresses all cumulant
averages of $J(t)$ in an external field in terms of equi-
librium averages.

Linear response theory [1-7] is fundamental to much present
day work in solid state physics, chemical physics, plasma
physics, etc. Its usefulness rests in the fact that the
response to an external field to first order is determined solely
by an equilibrium autocorrelation function. The extension of
linear response theory to include higher order terms was
discussed already in the 1950's [6,8]. In contrast to the linear
case, the higher order terms cannot be expressed in terms of
equilibrium correlation functions of the degree of freedom under
consideration [9]. The exact nonlinear response theory is
complex and has found little application. There is also the
question of the convergence of the formal expansion in the
external field. Strong fields may induce e. g. phase transitions
or self organization, information about which one does not expect
to be hidden in the equilibrium fluctuations. Despite these
reservations, one may ask whether a theory which predicts the
nonlinear response from equilibrium fluctuations does exist, at
least as a reasonable approximation applicable not too far from
equilibrium. In an attempt to answer this question, this paper
discusses and generalizes a little known ansatz for "non-linear
response theory", due to Stratonovich [10]. The ansatz is here
derived from the maximum entropy principle. Some simple examples
are given and the validity of the ansatz is discussed. It is
argued that the ansatz represents, in a sense, the simplest way a
system may become nonlinear.

The degree of freedom of interest is denoted by Q , it may be
microscopic or macroscopic. The underlying dynamics is assumed
to be classical and Q is assumed to be invariant under time-
reversal. Q couples to an external field E via a term $-EQ$
in the Hamiltonian. Only the case of a time-independent external

3

field will be considered. It is convenient to discuss response and fluctuations in terms of $J(t) \equiv \dot{Q}(t)$. In general, one is interested in not only the average $\langle J \rangle_E$ but also in the external field autocorrelation function and perhaps higher order averages. To calculate these quantities one needs to know the probability of any $J(t)$-fluctuation in the external field, $P_E[J(t)]$. As mentioned above, even a complete knowledge of the equilibrium fluctuations, $P_0[J(t)]$, in general is not enough to determine $P_E[J(t)]$. The task of finding $P_E[J(t)]$ may be viewed as a missing information problem. In an external field there is a certain rate of energy dissipation, and no more than this and $P_0[J(t)]$ is known a priori. The maximum entropy formalism is a general method that, based on the insufficient information available, gives a least biased estimate of probabilities [11, 12]. In applications to a continuous problem a reference measure is needed. In the present case, in order to have a smooth transition to the zero field case this measure must be $P_0[J(t)]$. The maximum entropy requirement leads to [11,12]

$$P_E\left[J(t)\right] = N^{-1} P_0\left[J(t)\right] \exp\left\{- \lambda E \int_{-\infty}^{\infty} J(t) dt\right\} \qquad (1)$$

where N is a normalization constant and $\lambda = \lambda(E)$ is a Lagrangian multiplier. Normally, one would now proceed to determine λ from the constraint, i. e. the energy dissipation rate. In this case, however, λ is determined by fundamental requirements of statistical mechanics. As shown by Bochkov and Kuzovlev [13,14], the time-reversal invariance of the microscopic equations of motion implies

$$\frac{P_E\left[J(t)\right]}{P_E\left[-J(-t)\right]} = \exp\left\{\beta E \int_{-\infty}^{\infty} J(t) dt\right\} \qquad (2)$$

where β is the inverse temperature. Equation (2) is derived by assuming thermal equilibrium at $t=-\infty$ followed by a decoupling of the heat bath and evolution according to the canonical equations of motion for the system interacting with the external field. Alternatively, the heat bath may be thought of as part of the system. These assumptions are identical to those used by Kubo in deriving linear response theory [6]. Equation (2) is also valid for any system which is described by a master equation; in this case Eq. (2) follows from the principle of detailed balance. Since $P_0[J(t)]$ is time-reversal invariant, Eqs. (1) and (2) imply $\lambda = -\beta/2$ for all E, i. e.

$$P_E[J(t)] = N^{-1} P_0[J(t)] \exp\left\{ \beta/2 \, E \int_{-\infty}^{\infty} J(t)\,dt \right\}. \qquad (3)$$

Equation (3) allows one to calculate all higher order cumulant averages of J in the external field, in terms of equilibrium cumulants. The cumulants are defined by the generating functional

$$D[u(\tau); E] = Ln \left\langle \exp\left\{ \int_{-\infty}^{\infty} u(\tau) J(\tau)\,d\tau \right\} \right\rangle_E$$

$$= \sum_{n=1}^{\infty} \frac{1}{n!} \int_{-\infty}^{\infty} dt_1 \cdots dt_n \left\langle J(t_1), \cdots, J(t_n) \right\rangle_E u(t_1) \cdots u(t_n) \qquad (4)$$

and Eq. (3) implies

$$D[u(\tau); E] = D[u(\tau) + \beta/2 E; 0] - D[\beta/2 E; 0]. \qquad (5)$$

From Eq. (5) the nonequilibrium cumulants may be found as derivatives with respect to $u(\tau)$ at $u \equiv 0$.

For the average of J one finds from Eq. (5)

$$\langle J \rangle_E = \sum_{n=0}^{\infty} \frac{1}{n!} \left(\frac{\beta E}{2} \right)^n \int_{-\infty}^{\infty} dt_1 \cdots dt_n \langle J(0), J(t_1), \cdots, J(t_n) \rangle_0 \ . \qquad (6)$$

The first order term is that predicted by linear response theory. Note that, for a macroscopic Q , Eq. (6) is consistent in the thermodynamic limit since cumulants are additive for independently fluctuating quantities. An identity for the $(n+1)$'th cumulant average of $\Delta Q(t) = Q(t) - Q(0)$, $\lim_{t \to \infty} t^{-1} \langle \Delta Q^{(n+1)}(t) \rangle_0 =$

$$= \int_{-\infty}^{\infty} dt_1 \cdots dt_n \langle J(0), J(t_1), \cdots, J(t_n) \rangle_0 \ , \text{ allows one to rewrite Eq. (6) as}$$

$$\langle J \rangle_E = \lim_{t \to \infty} t^{-1} \frac{d}{du} \ln \langle e^{u \Delta Q(t)} \rangle_0 \Big|_{u = \beta/2 E} \ . \qquad (7)$$

As a simple example of Eq. (7), consider a particle performing a random walk in one dimension on a lattice with lattice constant a . Q is the coordinate and J the velocity of the particle. If there are N jumps in time t it is easy to see that $\langle e^{u \Delta Q(t)} \rangle_0 = \cosh^N(ua)$. Since N is Poisson distributed around a mean $\overline{N} = \Gamma t$, one has

$$\langle e^{u \Delta Q(t)} \rangle_0 = e^{-\overline{N}} \sum_{N=0}^{\infty} \frac{\overline{N}^N}{N!} \cosh^N(ua) = e^{\overline{N}(\cosh(ua)-1)} \qquad (8)$$

which implies

$$\langle v \rangle_E = \Gamma a \sinh\left(\beta/2 E a \right). \qquad (9)$$

This is the correct result if the random walk is realized as the low temperature limit of a particle in a symmetric periodic potential obeying a Langevin equation; the well-known Eq. (9) follows from the fact that the field lowers the barrier for jumps

in the direction of E and increases the barrier for jumps opposite to E . As another example of Eq. (7), consider the case when Q is the x-coordinate of an atom in a liquid. Then Eq. (7) expresses the velocity of the atom in a field in the x-direction acting only on the atom, in terms of the equilibrium incoherent intermediate scattering function $F_s(k,t)$:

$$\langle v \rangle_E = \lim_{t \to \infty} (it)^{-1} \frac{\partial}{\partial k} \ln F_s(k,t) \Big|_{k=-\frac{\beta E}{2i}} \qquad (10)$$

For simple gaussian diffusion $F_s(k,t) = \exp(-Dk^2 t)$ [15]. In this case the response is exactly linear and Eq. (10) reduces to the Nernst-Einstein relation between mobility and diffusion constant. A more realistic fit to experiment is the prediction of the jump-diffusion model [15,16] $F_s(k,t) = \exp[-Dk^2 t/(1+Dk^2\tau_0)]$. From this, Eq. (10) predicts the onset of nonlinearity at fields for which $El\beta \simeq 1$ where the length $l = \sqrt{D\tau_0}$ in fits to data is of order one interatomic spacing.

For the external field autocorrelation function Eq. (5) implies

$$\langle J(0), J(t) \rangle_E = \langle J(0), J(t) \rangle_0 + \frac{\beta E}{2} \int_{-\infty}^{\infty} dt_1 \langle J(0), J(t), J(t_1) \rangle_0$$

$$+ \frac{1}{2} \left(\frac{\beta E}{2}\right)^2 \iint_{-\infty}^{\infty} dt_1 dt_2 \langle J(0), J(t), J(t_1), J(t_2) \rangle_0 + \cdots \qquad (11)$$

An example is the case when J is the electric current. For a system with frequency-independent conductivity the zeroth order term is a delta function, giving rise to white noise. In most cases the next term is zero by symmetry and the so-called excess current noise is given by the second order term. Excess current noise is ubiquitous and usually has a 1/f spectrum [17-19]. A

number of random walk models have been studied to gain a better understanding of the phenomenon. In these models one finds [20–23]

$$\langle J(0), J(t) \rangle_E = (\beta E)^2 \int_0^t dt_2 \int_0^{t_2} dt_1 \langle J(0), J(t), J(t_1), J(t_2) \rangle_0 + \cdots \quad (t > 0) \quad (12)$$

which is equivalent to Eq. (11) because in random walk models $\langle J(t_1), J(t_2), J(t_3), J(t_4) \rangle$ is non-zero only if $t_1 \approx t_2$ and $t_3 \approx t_4$ (or permutations thereof) where $t_1 \approx t_2$ means $t_1 - t_2$ is a microscopic time [20,21].

The similarity between the right hand sides of Eqs. (6) and (11) suggests that a relation exists between $\langle J \rangle_E$ and $\langle J(0), J(t) \rangle_E$. It is easy to show that

$$\frac{d}{dE} \langle J \rangle_E = -\frac{\beta}{2} \int_{-\infty}^{\infty} \langle J(0), J(t) \rangle_E \, dt. \quad (13)$$

Actually, this result is not approximate but a special case of an exact theorem due to Peterson [24].

Since higher than second order cumulants are zero for a gaussian system, the maximum entropy ansatz implies the response is exactly linear whenever the equilibrium J-fluctuations are gaussian. This is analogous to what happens in equilibrium statistical mechanics. A magnetic system, for instance, has a field independent susceptibility only if the free energy is quadratic in the magnetization. Note that nongaussian fluctuations survive in the thermodynamic limit, the central limit theorem notwithstanding. A simple example of this in statistical mechanics is energy fluctuations in the canonical ensemble. If the energy fluctuations are strictly gaussian, the average energy is linear in β so the specific heat varies as -2. Whenever this is not the case, the energy fluctuations are

nongaussian.

The maximum entropy formalism has a long history of applications to the problem of estimating the density matrix for a nonequilibrium system. This leads to a generalization of equilibrium statistical mechanics which takes into account the limited amount of information available about the system [25-29]. Some applications of the formalism characterize the non-equilibrium system by its energy dissipation rate [30,31]. As shown above, when applied to the external field induced "non-equilibrium" in the J(t)-space, this idea leads to definite predictions of the nonlinear response in terms of equilibrium fluctuations. The resulting ansatz Eq. (5) has been discussed briefly by Bochkov and Kuzovlev [13], referring to earlier work by Stratonovich [10]. Only the case $u(\tau)=$const. was considered and the discussion was limited to Markovian systems. No justification of the ansatz was given except that it satisfies the requirement of statistical mechanics Eq. (2). The maximum entropy property of the ansatz, on the other hand, shows that it is the most reasonable, given only a knowledge of the equilibrium fluctuations. This does not guaranty the ansatz is correct, however. To look into this question, we first discuss the consequences of a phenomenological Langevin equation for Q and then an exact result.

Suppose Q obeys a Langevin equation $\dot{Q} = C F(Q) + \zeta(t)$ where $F(Q)=F_0(Q)+E$ is the generalized force and $\zeta(t)$ is a gaussian white noise term. Then the path-probability is given by [32,33] $P[Q(t)] = N^{-1}\exp\{-\beta/(4C)\int_{-\infty}^{\infty}[\dot{Q}(t)-CF(Q(t))]^2 dt\}$, or

$$P_E\left[Q(t)\right] = N^{-1} P_0\left[Q(t)\right] \exp\left\{\frac{\beta}{2}E\int_{-\infty}^{\infty}\dot{J}(t)\,dt\right\}\exp\left\{-\frac{\beta}{2}EC\int_{-\infty}^{\infty}F_0(Q(t))\,dt\right\}. \quad (14)$$

The transformation from $Q(t)$ to $\dot{Q}(t)$ is linear. Therefore, Eq. (14) implies that the maximum entropy ansatz leads to correct results whenever the last term is unimportant. As an example, consider again a particle in one dimension in a periodic potential at low temperature. Because of the $P_o[Q(t)]$ factor, the important paths fluctuate for some time around a potential energy minimum before suddenly "jumping" to a new minimum. For these paths the last term of Eq. (14) is almost independent of the number of minima traversed and may be ignored for the calculation of $\langle \Delta Q(t) \rangle_E$ for large t. Thus, the maximum entropy ansatz leads to correct results in this case, as already shown in Eq. (9).

A result due to Furukawa sheds more light on the maximum entropy ansatz. He showed that, for slowly fluctuating $J(t)$, the exact microscopic equation of motion implies [34]

$$P_E\left[J(t)\right] = N^{-1} P_o\left[J(t)\right] \exp\left\{ \tfrac{\beta}{2} E \int_{-\infty}^{\infty} J(t)\,dt + O(E^2) \right\}. \tag{15}$$

Equation (15) shows that there are two different ways a system may become nonlinear: Either 1) as an interplay between nongaussian equilibrium J-fluctuations and the first order term, or 2) as a result of the higher order terms becoming important. The first case is when the maximum entropy ansatz gives correct results; this may be referred to as a "simple" nonlinearity since it results from the very same term in Eq. (15) that gives rise to the linear response. Upon increasing the external field, a system may pass from linear through simple nonlinear response to finally the "complex" non-linear response due to the higher order terms, or it may go directly from the linear to complex nonlinear response. The maximum entropy ansatz is never correct for the

latter systems, and in the former case it should only be trusted at not too large external fields.

To summarize, it has been shown that the maximum entropy formalism in conjunction with statistical mechanics leads to unique predictions for the external field cumulant averages of $J(t)$ in terms of equilibrium averages. The ansatz Eq. (3) may be justified in other ways. It corresponds to keeping only the first order term in Eq. (15) which is exact for slowly fluctuating $J(t)$. This term is responsible for the linear response, so the ansatz is clearly the simplest way to extrapolate linear response theory into the nonlinear regime. The extrapolation has the property that the response is exactly linear if the equilibrium J-fluctuations are gaussian. If Q obeys a Langevin equation, the ansatz is correct whenever the last term of Eq. (14) is unimportant; for slowly fluctuating $J(t)$ the requirement of consistency between Eqs. (14) and (15) implies that the extra terms of both equations must be insignificant and the maximum entropy ansatz must be correct.

The maximum entropy ansatz solves a conceptual problem, but open questions remain regarding the validity and the practical value of the ansatz. One obvious problem is that the ansatz predicts a universal form of the nonlinear response while one expects the response to depend on the way heat generated by the external field is removed. On the other hand, the ansatz only makes sense in situations where the temperature is almost constant throughout the sample (because the temperature enters into Eq. (5)). In bulk cases this requirement can be satisfied for a given external field by working with a sufficiently small sample; in this limit the problem of heating becomes insignificant. -- Equation (15) implies the ansatz can only be

11

valid at not too large external fields. Also, Eq. (15) implies
that a system may become nonlinear either by first exhibiting the
"simple" nonlinearity predicted by the ansatz before becoming
"complex" nonlinear, or by going directly from the linear to the
complex nonlinear regime. In this connection it should be noted
that all formulas given above may be generalized to several
degrees of freedom. One may speculate that, by including the
"mode-coupling" terms to other relevant degrees of freedom, a
complex nonlinearity may be converted to a simple, thus
extending the validity of the ansatz. -- Even when the maximum
entropy ansatz is valid, the practical value of it is not clear
at present. It is possible that the calculation of the
equilibrium higher order cumulant averages requires at least as
much effort as a direct calculation of the nonlinear response.
Certainly, this is the case for the above discussed simple random
walk in one dimension. On the other hand, Eq. (12) has provided
insight into the problem of 1/f noise in conductors. And, for
instance, Eq. (10) gives explicit predictions for the response of
a single atom to an external force, based on a knowledge of the
equilibrium intermediate incoherent scattering function, a
quantity which has been studied extensively [15].

Acknowledgements

The author is indebted to Peter Wolynes for numerous helpful discussions and suggestions relating to this work, and also for his most kind hospitality during the time the work was carried out. This work was supported by the Danish Natural Science Research Council.

References

1. H. Nyquist, Phys. Rev. **32**, 110 (1928).

2. L. Onsager, Phys. Rev. **37**, 405 and **38**, 2265 (1931).

3. J. G. Kirkwood, J. Chem. Phys. **14**, 180 (1946).

4. H. B. Callen and T. A. Welton, Phys. Rev. **83**, 34 (1951).

5. M. S. Green, J. Chem. Phys. **20**, 1281 (1952) .

6. R. Kubo, J. Phys. Soc. Japan **12**, 570 (1957).

7. L. P. Kadanoff and P. C. Martin, Ann. Phys. **24**, 419 (1963).

8. W. Bernard and H. B. Callen, Rev. Mod. Phys. **31**, 1017 (1959).

9. R. L. Stratonovich, Zh. Eksp. Teor. Fiz. **58**, 1612 (1970) [Sov. Phys. JETP **31**, 864 (1970)].

10. R. L. Stratonovich, Vestnik Mosk. Univ. Fiz.-Astr. **5**, 16 (1962) [in russian].

11. E. T. Jaynes, Phys. Rev. **106**, 620 and **108**, 171 (1957).

12. "The Maximum Entropy Formalism", ed. R. Levine and M. Tribus (The MIT Press, Cambridge, Massachusetts, 1979).

13. G. N. Bochkov and Yu. E. Kuzovlev, Zh. Eksp. Teor. Fiz. **72**, 238 (1977) [Sov. Phys. JETP **45**, 125 (1977)].

14. G. N. Bochkov and Yu. E. Kuzovlev, Physica **106A**, 443 and **106A**, 480 (1981).

15. J. P. Boon and S. Yip, "Molecular Hydrodynamics" (McGraw Hill, New York, 1980).

16. K. S. Singwi and A. Sjölander, Phys. Rev. **119**, 863 (1960).

17. D. A. Bell, J. Phys. C **13**, 4425 (1980).

18. P. Dutta and P. M. Horn, Rev. Mod. Phys. **53**, 497 (1981).

19. M. B. Weissman, Rev. Mod. Phys. **60**, 537 (1988).

20. C. J. Stanton and M. Nelkin, J. Stat. Phys. **37**, 1 (1984).

21. Th. M. Nieuwenhuizen and M. H. Ernst, J. Stat. Phys. **41**, 773

(1985).

22. J. Machta, M. Nelkin, Th. M. Nieuwenhuizen, and M. H. Ernst, Phys. Rev. B **31**, 7636 (1985).

23. J. C. Dyre, Phys. Rev B **37**, 10143 (1988).

24. R. L. Peterson, Rev. Mod. Phys. **39**, 69 (1967).

25. E. T. Jaynes, in: "Statistical Physics" (1963 Brandeis Lectures, Vol. 3), ed. W. K. Ford (Benjamin, New York, 1963), p. 181.

26. H. Schwegler, Z. Naturforsch. **20A**, 1543 (1965).

27. B. Robertson, Phys. Rev. **144**, 151 (1966).

28. D. N. Zubarev and V. P. Kalashnikov, Physica **46**, 550 (1970).

29. W. T. Grandy Jr., Phys. Rep. **62**, 175 (1980).

30. H. Sato, Prog. Theor. Phys. **57**, 1115 (1977).

31. T. M. Brown, J. Phys. A **15**, 2285 (1982).

32. L. Onsager and S. Machlup, Phys. Rev. **91**, 1505 (1953).

33. H. Risken, "The Fokker-Planck Equation" (Springer, Berlin, 1984).

34. H. Furukawa, Prog. Theor. Phys. **54**, 370 (1975).
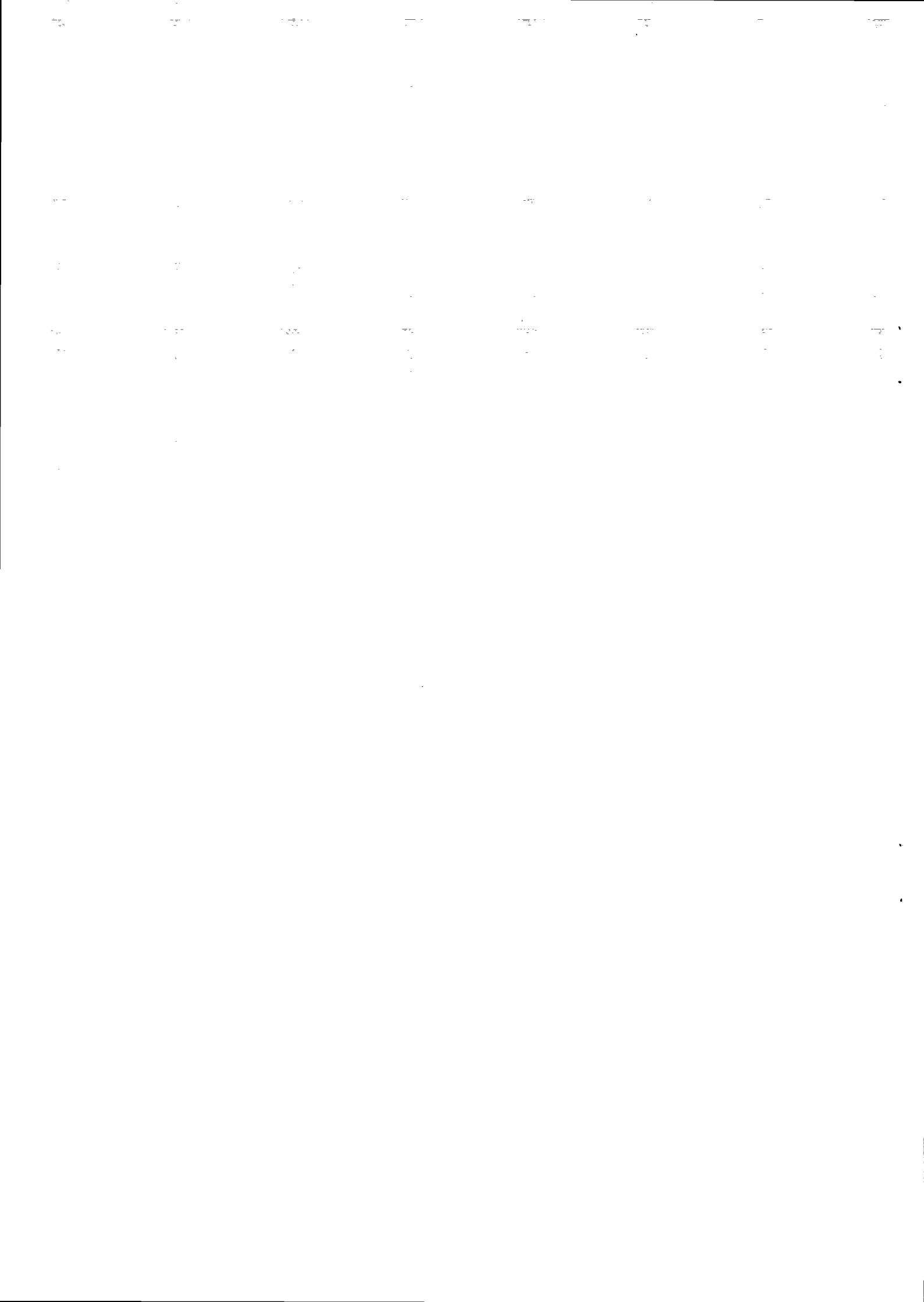
1/78 "TANKER OM EN PRAKSIS" - et matematikprojekt.
Projektrapport af: Anne Jensen, Lena Linden-
skov, Marianne Kesselhahn og Nicolai Lomholt.
Vejleder: Anders Madsen

2/78 "OPTIMERING" - Menneskets forøgede beher-
skelsesmuligheder af natur og samfund.
Projektrapport af: Tom J. Andersen, Tommy
R. Andersen,Gert Krenøe og Peter H. Lassen
Vejleder: Bernhelm Boss.

3/78 "OPGAVESAMLING", breddekursus i fysik.
Af: Lasse Rasmussen, Aage Bonde Kræmmer
og Jens Højgaard Jensen.

4/78 "TRE ESSAYS" - om matematikundervisning,
matematiklæreruddannelsen og videnskabs-
rindalismen.
Af: Mogens Niss
Nr. 4 er p.t. udgået.

5/78 "BIBLIOGRAFISK VEJLEDNING til studiet af
DEN MODERNE FYSIKS HISTORIE".
Af: Helge Kragh.
Nr. 5 er p.t. udgået.

6/78 "NOGLE ARTIKLER OG DEBATINDLÆG OM - lærer-
uddannelse og undervisning i fysik, og - de
naturvidenskabelige fags situation efter
studenteroprøret".
Af: Karin Beyer, Jens Højgaard Jensen og
Bent C. Jørgensen.

7/78 "MATEMATIKKENS FORHOLD TIL SAMFUNDSØKONOMIEN".
Af: B.V. Gnedenko.
Nr. 7 er udgået.

8/78 "DYNAMIK OG DIAGRAMMER". Introduktion til
energy-bond-graph formalismen.
Af: Peder Voetmann Christiansen.

9/78 "OM PRAKSIS' INDFLYDELSE PÅ MATEMATIKKENS UD -
VIKLING". - Motiver til Kepler's: "Nova Stere-
ometria Doliorum Vinariom".
Projektrapport af: Lasse Rasmussen .
Vejleder: Anders Madsen.

10/79 "TERMODYNAMIK I GYMNASIET".
Projektrapport af: Jan Christensen og Jeanne
Mortensen,
Vejledere: Karin Beyer og Peder Voetmann
Christiansen.

11/79 "STATISTISKE MATERIALER".
Af: Jørgen Larsen.

12/79 "LINEÆRE DIFFERENTIALLIGNINGER OG DIFFEREN-
TIALLIGNINGSSYSTEMER".
Af: Mogens Brun Heefelt.
Nr. 12 er udgået.

13/79 "CAVENDISH'S FORSØG I GYMNASIET".
Projektrapport af: Gert Kreinøe.
Vejleder: Albert Chr. Paulsen.

14/79 "BOOKS ABOUT MATHEMATICS: History, Philosophy,
Education, Models, System Theory, and Works of".
Af: Else Høyrup.
Nr. 14 er p.t. udgået.

15/79 "STRUKTUREL STABILITET OG KATASTROFER i systemer
i og udenfor termodynamisk ligevægt".
Specialeopgave af: Leif S. Striegler.
Vejleder: Peder Voetmann Ckristiansen.

16/79 "STATISTIK I KRÆFTFORSKNINGEN".
Projektrapport af: Michael Olsen og Jørn Jensen.
Vejleder: Jørgen Larsen.

17/79 "AT SPØRGE OG AT SVARE i fysikundervisningen".
Af: Albert Christian Paulsen.

18/79 "MATHEMATICS AND THE REAL WORLD", Procee-
dings af an International Workshop, Ros-
kilde University Centre, Denmark, 1978.
Preprint.
Af: Bernhelm Booss og Mogens Niss (eds.)

19/79 "GEOMETRI, SKOLE OG VIRKELIGHED".
Projektrapport af: Tom J. Andersen,Tommy
R. Andersen og Per H.H. Larsen.
Vejleder: Mogens Niss.

20/79 "STATISTISKE MODELLER TIL BESTEMMELSE AF SIKRE
DOSER FOR CARCINOGENE STOFFER".
Projektrapport af: Michael Olsen og Jørn Jensen.
Vejleder: Jørgen Larsen

21/79 "KONTROL I GYMNASIET-FORMÅL OG KONSEKVENSER".
Projektrapport af: Crilles Bacher, Per S.Jensen,
Preben Jensen og Torben Nysteen.

22/79 "SEMIOTIK OG SYSTEMEGENSKABER (1)".
1-port lineært response og støj i fysikken.
Af: Peder Voetmann Christiansen.

23/79 "ON THE HISTORY AF EARLY WAVE MECHANICS - with
special emphasis on the role af realitivity".
Af: Helge Kragh.

24/80 "MATEMATIKOPFATTELSER HOS 2.G'ERE".
a+b 1. En analyse. 2. Interviewmateriale.
Projektrapport af: Jan Christensen og Knud
Lindhardt Rasmussen.
Vejleder: Mogens Niss.

25/80 "EKSAMENSOPGAVER", Dybdemodulet/fysik 1974-79.

26/80 "OM MATEMATISKE MODELLER".
En projektrapport og to artikler.
Af: Jens Højgaard Jensen m.fl.

27/80 "METHODOLOGY AND PHILOSOPHY AF SCIENCE IN PAUL
DIRAC's PHYSICS".
Af: Helge Kragh.

28/80 "DIELEKTRISK RELAXATION - et forslag til en ny
model bygget på væskernes viscoelastiske egen-
skaber".
Projektrapport af: Gert Kreinøe.
Vejleder: Niels Boye Olsen.

29/80 "ODIN - undervisningsmateriale til et kursus i
differentialligningsmodeller".
Projektrapport af: Tommy R. Andersen, Per H.H.
Larsen og Peter H. Lassen.
Vejleder: Mogens Brun Heefelt.

30/80 "FUSIONSENERGIEN - - - ATOMSAMFUNDETS ENDESTATI-
ON".
Af: Oluf Danielsen.
Nr. 30 er udgået.

31/80 "VIDENSKABSTEORETISKE PROBLEMER VED UNDERVISNINGS -
SYSTEMER BASERET PÅ MÆNGDELÆRE".
Projektrapport af: Troels Lange og Jørgen Kar-
rebæk.
Vejleder: Stig Andur Pedersen.
Nr. 31 er p.t. udgået.

32/80 "POLYMERE STOFFERS VISCOELASTISKE EGENSKABER -
BELYST VED HJÆLP AF MEKANISKE IMPEDANSMÅLIN -
GER MÖSSBAUEREFFEKTMÅLINGER".
Projektrapport af: Crilles Bacher og Preben
Jensen.
Vejledere: Niels Boye Olsen og Peder Voet-
mann Christiansen.

33/80 "KONSTITUERING AF FAG INDEN FOR TEKNISK - NATUR-
VIDENSKABELIGE UDDANNELSER. I-II".
Af: Arne Jakobsen.

34/80 "ENVIRONMENTAL IMPACT AF WIND ENERGY UTILIZA-
TION".
ENERGY SERIES NO. I.
Af: Bent Sørensen
Nr. 34 er udgået.

35/80 "HISTORISKE STUDIER I DEN NYERE ATOMFYSIKS UDVIKLING".
Af: Helge Kragh.

36/80 "HVAD ER MENINGEN MED MATEMATIKUNDERVISNINGEN?".
Fire artikler.
Af: Mogens Niss.

37/80 "RENEWABLE ENERGY AND ENERGY STORAGE".
ENERGY SERIES NO. 2.
Af: Bent Sørensen.

_____

38/81 "TIL EN HISTORIETEORI OM NATURERKENDELSE, TEKNOLOGI
OG SAMFUND".
Projektrapport af: Erik Gade, Hans Hedal, Henrik Lau
og Finn Physant.
Vejledere: Stig Andur Pedersen, Helge Kragh og Ib
Thiersen.
Nr. 38 er p.t. udgået.

39/81 "TIL KRITIKKEN AF VÆKSTØKONOMIEN".
Af: Jens Højgaard Jensen.

40/81 "TELEKOMMUNIKATION I DANMARK - oplæg til en tekno-
logivurdering".
Projektrapport af: Arne Jørgensen, Bruno Petersen og
Jan Vedde.
Vejleder: Per Nørgaard.

41/81 "PLANNING AND POLICY CONSIDERATIONS RELATED TO THE
INTRODUCTION OF RENEWABLE ENERGY SOURCES INTO ENER-
GY SUPPLY SYSTEMS".
ENERGY SERIES NO. 3.
Af: Bent Sørensen.

42/81 "VIDENSKAB TEORI SAMFUND - En introduktion til materialis-
tiske videnskabsopfattelser".
Af: Helge Kragh og Stig Andur Pedersen.

43/81 1."COMPARATIVE RISK ASSESSMENT OF TOTAL ENERGY SYSTEMS".
2."ADVANTAGES AND DISADVANTAGES OF DECENTRALIZATION".
ENERGY SERIES NO. 4.
Af: Bent Sørensen.

44/81 "HISTORISKE UNDERSØGELSER AF DE EKSPERIMENTELLE FOR-
UDSÆTNINGER FOR RUTHERFORDS ATOMMODEL".
Projektrapport af: Niels Thor Nielsen.
Vejleder: Bent C. Jørgensen.

_____

45/82 Er aldrig udkommet.

46/82 "EKSEMPLARISK UNDERVISNING OG FYSISK ERKENDESE-
1+11 ILLUSTRERET VED TO EKSEMPLER".
Projektrapport af: Torben O.Olsen, Lasse Rasmussen og
Niels Dreyer Sørensen.
Vejleder: Bent C. Jørgensen.

47/82 "BARSEBÄCK OG DET VÆRST OFFICIELT-TÆNKELIGE UHELD".
ENERGY SERIES NO. 5.
Af: Bent Sørensen.

48/82 "EN UNDERSØGELSE AF MATEMATIKUNDERVISNINGEN PÅ ADGANGS-
KURSUS TIL KØBENHAVNS TEKNIKUM".
Projektrapport af: Lis Eilertzen, Jørgen Karrebæk, Troels
Lange, Preben Nørregaard, Lissi Pedesen, Laust Rishøj,
Lill Røn og Isac Showiki.
Vejleder: Mogens Niss.

49/82 "ANALYSE AF MULTISPEKTRALE SATELLITBILLEDER".
Projektrapport af: Preben Nørregaard.
Vejledere: Jørgen Larsen og Rasmus Ole Rasmussen.

50/82 "HERSLEV - MULIGHEDER FOR VEDVARENDE ENERGI I EN
LANDSBY".
ENERGY SERIES NO. 6.
Rapport af: Bent Christensen, Bent Hove Jensen, Dennis
B. Møller, Bjarne Laursen, Bjarne Lillethorup og Jacob
Mørch Pedersen.
Vejleder: Bent Sørensen.

51/82 "HVAD KAN DER GØRES FOR AT AFHJÆLPE PIGERS BLOKERING
OVERFOR MATEMATIK ?"
Projektrapport af: Lis Eilertzen, Lissi Pedersen, Lill
Røn og Susanne Stender.

52/82 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS".
Af: Bernhelm Booss og Krzysztof Wojciechowski.

53/82 "THE CONSTITUTION OF SUBJECTS IN ENGINEERING
EDUCATION".
Af: Arne Jacobsen og Stig Andur Pedersen.

54/82 "FUTURES RESEARCH" - A Philosophical Analysis
of Its Subject-Matter and Methods.
Af: Stig Andur Pedersen og Johannes Witt-Hansen.

55/82 "MATEMATISKE MODELLER" - Litteratur på Roskilde
Universitetsbibliotek.
En biografi.
Af: Else Høyrup.

Vedr. tekst nr. 55/82 se også tekst nr. 62/83.

56/82 "EN - TO - MANGE" -
En undersøgelse af matematisk økologi.
Projektrapport af: Troels Lange.
Vejleder: Anders Madsen.

_____

57/83 "ASPECT EKSPERIMENTET"-
Skjulte variable i kvantemekanikken?
Projektrapport af: Tom Juul Andersen.
Vejleder: Peder Voetmann Christiansen.
Nr. 57 er udgået.

58/83 "MATEMATISKE VANDRINGER" - Modelbetragtnin-
ger over spredning af dyr mellem småbiotoper
i agerlandet.
Projektrapport af: Per Hammershøj Jensen og
Lene Vagn Rasmussen.
Vejleder: Jørgen Larsen.

59/83 "THE METHODOLOGY OF ENERGY PLANNING".
ENERGY SERIES NO. 7.
Af: Bent Sørensen.

60/83 "MATEMATISK MODEKSPERTISE"- et eksempel.
Projektrapport af: Erik O. Gade, Jørgen Kar-
rebæk og Preben Nørregaard.
Vejleder: Anders Madsen.

61/83 "FYSIKS IDEOLOGISKE FUNKTION, SOM ET EKSEMPEL
PÅ EN NATURVIDENSKAB - HISTORISK SET".
Projektrapport af: Annette Post Nielsen.
Vejledere: Jens Høyrup, Jens Højgaard Jensen
og Jørgen Vogelius.

62/83 "MATEMATISKE MODELLER" - Litteratur på Roskilde
Universitetsbibliotek.
En biografi 2. rev. udgave.
Af: Else Høyrup.

63/83 "CREATING ENERGY FUTURES:A SHORT GUIDE TO ENER-
GY PLANNING".
ENERGY SERIES No. 8.
Af: David Crossley og Bent Sørensen.

64/83 "VON MATEMATIK UND KRIEG".
Af: Berhelm Booss og Jens Høyrup.

65/83 "ANVENDT MATEMATIK - TEORI ELLER PRAKSIS".
Projektrapport af: Per Hedegård Andersen, Kir-
sten Habekost, Carsten Holst-Jensen, Annelise
von Moos, Else Marie Pedersen og Erling Møller
Pedersen.
Vejledere: Bernhelm Booss og Klaus Grünbaum.

66/83 "MATEMATISKE MODELLER FOR PERIODISK SELEKTION
I ESCHERICHIA COLI".
Projektrapport af: Hanne Lisbet Andersen, Ole
Richard Jensen og Klavs Frisdahl.
Vejledere: Jørgen Larsen og Anders Hede Madsen.

67/83 "ELEPSOIDE METODEN - EN NY METODE TIL LINEÆR
PROGRAMMERING?"
Projektrapport af: Lone Biilmann og Lars Boye.
Vejleder: Mogens Brun Heefelt.

68/83 "STOKASTISKE MODELLER I POPULATIONSGENETIK"
- til kritikken af teoriladede modeller.
Projektrapport af: Lise Odgård Gade, Susanne
Hansen, Michael Hviid og Frank Mølgård Olsen.
Vejleder: Jørgen Larsen.

69/83 "ELEVFORUDSÆTNINGER I FYSIK"
- en test i 1.g med kommentarer.
Af: Albert C. Paulsen.

70/83 "INDLÆRINGS - OG FORMIDLINGSPROBLEMER I MATEMATIK
PÅ VOKSENUNDERVISNINGSNIVEAU".
Projektrapport af: Hanne Lisbet Andersen, Tor-
ben J. Andreasen, Svend Åge Houmann, Helle Gle-
rup Jensen, Keld Fl. Nielsen, Lene Vagn Ras-
mussen.
Vejleder: Klaus Grünbaum og Anders Hede Madsen.

71/83 "PIGER OG FYSIK"
- et problem og en udfordring for skolen?
Af: Karin Beyer, Sussanne Blegaa, Birthe Olsen,
Jette Reich og Mette Vedelsby.

72/83 "VERDEN IFØLGE PEIRCE" - to metafysiske essays,
om og af C.S Peirce.
Af: Peder Voetmann Christiansen.

73/83 ""EN ENERGIANALYSE AF LANDBRUG"
- Økologisk contra traditionelt.
ENERGY SERIES NO. 9
Specialeopgave i fysik af: Bent Hove Jensen.
Vejleder: Bent Sørensen.

74/84 "MINIATURISERING AF MIKROELEKTRONIK" - om vi-
denskabeliggjort teknologi og nytten af at lære
fysik.
Projektrapport af: Bodil Harder og Linda Szko-
tak Jensen.
Vejledere: Jens Højgaard Jensen og Bent C. Jørgensen.

75/84 "MATEMATIKUNDERVISNINGEN I FREMTIDENS GYMNASIUM"
- Case: Linear programmering.
Projektrapport af: Morten Blomhøj, Klavs Frisdahl
og Frank Mølgaard Olsen.
Vejledere: Mogens Brun Heefelt og Jens Bjørneboe.

76/84 "KERNEKRAFT I DANMARK?" - Et høringssvar indkaldt
af miljøministeriet, med kritik af miljøstyrelsens
rapporter af 15. marts 1984.
ENERGY SERIES No. 10
Af: Niels Boye Olsen og Bent Sørensen.

77/84 "POLITISKE INDEKS - FUP ELLER FAKTA?"
Opinionsundersøgelser belyst ved statistiske
modeller.
Projektrapport af: Svend Åge Houmann, Keld Nielsen
og Susanne Stender.
Vejledere: Jørgen Larsen og Jens Bjørneboe.

78/84 "JÆVNSTRØMSLEDNINGSEVNE OG GITTERSTRUKTUT I
AMORFT GERMANIUM".
Specialrapport af: Hans Hedal, Frank C. Ludvigsen
og Finn C. Physant.
Vejleder: Niels Boye Olsen.

79/84 "MATEMATIK OG ALMENDANNELSE".
Projektrapport af: Henrik Coster, Mikael Wenner-
berg Johansen, Povl Kattler, Birgitte Lydholm
og Morten Overgaard Nielsen.
Vejleder: Bernhelm Booss.

80/84 "KURSUSMATERIALE TIL MATEMATIK B".
Af: Mogens Brun Heefelt.

81/84 "FREKVENSAFHÆNGIG LEDNINGSEVNE I AMORFT GERMANIUM".
Specialerapport af: Jørgen Wind Petersen og Jan
Christensen.
Vejleder: Niels Boye Olsen.

82/84 "MATEMATIK - OG FYSIKUNDERVISNINGEN I DET AUTO -
MATISEREDE SAMFUND".
Rapport fra et seminar afholdt i Hvidovre
25-27 april 1983.
Red.: Jens Højgaard Jensen, Bent C. Jørgensen
og Mogens Niss.

83/84 "ON THE QUANTIFICATION OF SECURITY":
PEACE RESEARCH SERIES NO. 1
Af: Bent Sørensen
nr. 83 er p.t. udgået

84/84 "NOGLE ARTIKLER OM MATEMATIK, FYSIK OG ALMENDANNELSE".
Af: Jens Højgaard Jensen, Mogens Niss m. fl.

85/84 "CENTRIFUGALREGULATORER OG MATEMATIK".
Specialerapport af: Per Hedegård Andersen, Carsten Holst-
Jensen, Else Marie Pedersen og Erling Møller Pedersen.
Vejleder: Stig Andur Pedersen.

86/84 "SECURITY IMPLICATIONS OF ALTERNATIVE DEFENSE OPTIONS
FOR WESTERN EUROPE".
PEACE RESEARCH SERIES NO. 2
Af: Bent Sørensen.

87/84 "A SIMPLE MODEL OF AC HOPPING CONDUCTIVITY IN DISORDERED
SOLIDS".
Af: Jeppe C. Dyre.

88/84 "RISE, FALL AND RESURRECTION OF INFINITESIMALS".
Af: Detlef Laugwitz.

89/84 "FJERNVARMEOPTIMERING".
Af: Bjarne Lillethorup og Jacob Mørch Pedersen.

90/84 "ENERGI I 1.G - EN TEORI FOR TILRETTELÆGGELSE".
Af: Albert Chr. Paulsen.

91/85 "KVANTETEORI FOR GYMNASIET".
1. Lærervejledning
Projektrapport af: Biger Lundgren, Henning Sten Hansen
og John Johansson.
Vejleder: Torsten Meyer.

92/85 "KVANTETEORI FOR GYMNASIET".
2. Materiale
Projektrapport af: Biger Lundgren, Henning Sten Hansen
og John Johansson.
Vejleder: Torsten Meyer.

93/85 "THE SEMIOTICS OF QUANTUM - NON - LOCALITY".
Af: Peder Voetmann Christiansen.

94/85 "TREENIGHEDEN BOURBAKI - generalen, matematikeren
og ånden".
Projektrapport af: Morten Blomhøj, Klavs Frisdahl
og Frank M. Olsen.
Vejleder: Mogens Niss.

95/85 "AN ALTERNATIV DEFENSE PLAN FOR WESTERN EUROPE".
PEACE RESEARCH SERIES NO. 3
Af: Bent Sørensen

96/85 "ASPEKTER VED KRAFTVARMEFORSYNING".
Af: Bjarne Lilletorup.
Vejleder: Bent Sørensen.

97/85 "ON THE PHYSICS OF A.C. HOPPING CONDUCTIVITY".
Af: Jeppe C. Dyre.

98/85 "VALGMULIGHEDER I INFORMATIONSALDEREN".
Af: Bent Sørensen.

99/85 "Der er langt fra Q til R".
Projektrapport af: Niels Jørgensen og Mikael Klintorp.
Vejleder: Stig Andur Pedersen.

100/85 "TALSYSTEMETS OPBYGNING".
Af: Mogens Niss.

101/85 "EXTENDED MOMENTUM THEORY FOR WINDMILLS IN
PERTURBATIVE FORM".
Af: Ganesh Sengupta.

102/85 OPSTILLING OG ANALYSE AF MATEMATISKE MODELLER, BELYST
VED MODELLER OVER KØERS FODEROPTAGELSE OG - OMSÆTNING".
Projektrapport af: Lis Eilertzen, Kirsten Habekost, Lill Røn
og Susanne Stender.
Vejleder: Klaus Grünbaum.

103/85 "ØDSLE KOLDKRIGERE OG VIDENSKABENS LYSE IDEER".
Projektrapport af: Niels Ole Dam og Kurt Jensen.
Vejleder: Bent Sørensen.

104/85 "ANALOGREGNEMASKINEN OG LORENZLIGNINGER".
Af: Jens Jæger.

105/85 "THE FREQUENCY DEPENDENCE OF THE SPECIFIC HEAT AF THE
GLASS REANSITION".
Af: Tage Christensen.

"A SIMPLE MODEL AF AC HOPPING CONDUCTIVITY".
Af: Jeppe C. Dyre.
Contributions to the Third International Conference
on the Structure of Non - Crystalline Materials held
in Grenoble July 1985.

106/85 "QUANTUM THEORY OF EXTENDED PARTICLES".
Af: Bent Sørensen.

107/85 "EN MYG GØR INGEN EPIDEMI",
- flodblindhed som eksempel på matematisk modelle-
ring af et epidemiologisk problem.
Projektrapport af: Per Hedegård Andersen, Lars Boye,
CarstenHolst Jensen, Else Marie Pedersen og Erling
Møller Pedersen.
Vejleder: Jesper Larsen.

108/85 "APPLICATIONS AND MODELLING IN THE MATEMATICS CUR -
RICULUM" - state and trends -
Af: Mogens Niss.

109/85 "COX I STUDIETIDEN" - Cox's regressionsmodel anvendt på
studenteroplysninger fra RUC.
Projektrapport af: Mikael Wennerberg Johansen, Poul Kat-
ler og Torben J. Andreasen.
Vejleder: Jørgen Larsen.

110/85 "PLANNING FOR SECURITY".
Af: Bent Sørensen

111/85 JORDEN RUNDT PÅ FLADE KORT".
Projektrapport af: Birgit Andresen, Beatriz Quinones
og Jimmy Staal.
Vejleder: Mogens Niss.

112/85 "VIDENSKABELIGGØRELSE AF DANSK TEKNOLOGISK INNOVATION
FREM TIL 1950 - BELYST VED EKSEMPLER".
Projektrapport af: Erik Odgaard Gade, Hans Hedal,
Frank C. Ludvigsen, Annette Post Nielsen og Finn
Physant.
Vejleder: Claus Bryld og Bent C. Jørgensen.

113/85 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS 11".
Af: Bernhelm Booss og Krzysztof Wojciechowski.

114/85 "ANVENDELSE AF GRAFISKE METODER TIL ANALYSE
AF KONTIGENSTABELLER".
Projektrapport af: Ione Biilmann, Ole R. Jensen
og Anne-Lise von Moos.
Vejleder: Jørgen Larsen.

115/85 "MATEMATIKKENS UDVIKLING OP TIL RENÆSSANCEN".
Af: Mogens Niss.

116/85 "A PHENOMENOLOGICAL MODEL FOR THE MEYER-
NELDEL RULE".
Af: Jeppe C. Dyre.

117/85 "KRAFT & FJERNVARMEOPTIMERING"
Af: Jacob Mørch Pedersen.
Vejleder: Bent Sørensen

118/85 "TILFÆLDIGHEDEN OG NØDVENDIGHEDEN IFØLGE
PEIRCE OG FYSIKKEN".
Af: Peder Voetmann Christiansen

119/86 "DET ER GANSKE VIST - - EUKLIDS FEMTE POSTULAT
KUNNE NOK SKABE RØRE I ANDEDAMMEN".
Af: Iben Maj Christiansen
Vejleder: Mogens Niss.

120/86 "ET ANTAL STATISTISKE STANDARDMODELLER".
Af: Jørgen Larsen

121/86 "SIMULATION I KONTINUERT TID".
Af: Peder Voetmann Christiansen.

122/86 "ON THE MECHANISM OF GLASS IONIC CONDUCTIVITY".
Af: Jeppe C. Dyre.

123/86 "GYMNASIEFYSIKKEN OG DEN STORE VERDEN".
Fysiklærerforeningen, IMFUFA, RUC.

124/86 "OPGAVESAMLING I MATEMATIK".
Samtlige opgaver stillet i tiden 1974-jan. 1986.

125/86 "UVBY,β - systemet - en effektiv fotometrisk spektral-
klassifikation af B-,A- og F-stjerner".
Projektrapport af: Birger Lundgren.

126/86 "OM UDVIKLINGEN AF DEN SPECIELLE RELATIVITETSTEORI".
Projektrapport af: Lise Odgaard & Linda Szkotak Jensen
Vejledere: Karin Beyer & Stig Andur Pedersen.

127/86 "GALOIS' BIDRAG TIL UDVIKLINGEN AF DEN ABSTRAKTE
ALGEBRA".
Projektrapport af: Pernille Sand, Heine Larsen &
Lars Frandsen.
Vejleder: Mogens Niss.

128/86 "SMÅKRYB" - om ikke-standard analyse.
Projektrapport af: Niels Jørgensen & Mikael Klintorp.
Vejleder: Jeppe Dyre.

129/86 "PHYSICS IN SOCIETY"
Lecture Notes 1983 (1986)
Af: Bent Sørensen

130/86 "Studies in Wind Power"
Af: Bent Sørensen

131/86 "FYSIK OG SAMFUND" - Et integreret fysik/historie-
projekt om naturanskuelsens historiske udvikling
og dens samfundsmæssige betingethed.
Projektrapport af: Jakob Heckscher, Søren Brønd,
Andy Wierød.
Vejledere: Jens Høyrup, Jørgen Vogelius,
Jens Højgaard Jensen.

132/86 "FYSIK OG DANNELSE"
Projektrapport af: Søren Brønd, Andy Wierød.
Vejledere: Karin Beyer, Jørgen Vogelius.

133/86 "CHERNOBYL ACCIDENT: ASSESSING THE DATA.
ENERGY SERIES NO. 15.
AF: Bent Sørensen.

134/87 "THE D.C. AND THE A.C. ELECTRICAL TRANSPORT IN AsSeTe SYSTEM"
Authors: M.B.El-Den, N.B.Olsen, Ib Høst Pedersen,
Petr Viscör

135/87 "INTUITIONISTISK MATEMATIKS METODER OG ERKENDELSES-
TEORETISKE FORUDSÆTNINGER"
MASTEMATIKSPECIALE: Claus Larsen
Vejledere: Anton Jensen og Stig Andur Pedersen

136/87 "Mystisk og naturlig filosofi: En skitse af kristendommens
første og andet møde med græsk filosofi"
Projektrapport af Frank Colding Ludvigsen
Vejledere: Historie: Ib Thiersen
Fysik: Jens Højgaard Jensen

137/87 "HOPMODELLER FOR ELEKTRISK LEDNING I UORDNEDE
FASTE STOFFER" - Resume af licentiatafhandling
Af: Jeppe Dyre
Vejledere: Niels Boye Olsen og
Peder Voetmann Christiansen.

166/88 "Grundbegreber i Sandsynligheds-
        regningen"

    Af: Jørgen Larsen

167a/88 "BASISSTATISTIK 1. Diskrete modeller"
        Af: Jørgen Larsen

167b/88 "BASISSTATISTIK 2. Kontinuerte
         modeller"

    Af: Jørgen Larsen

168/88 "OVERFLADEN AF PLANETEN MARS"
       Laboratorie-simulering og MARS-analoger
       undersøgt ved Mössbauerspektroskopi.

       Fysikspeciale af:

       Birger Lundgren

       Vejleder: Jens Martin Knudsen
                 Fys.Lab./HCØ

169/88 "CHARLES S. PEIRCE: MURSTEN OG MØRTEL
        TIL EN METAFYSIK."

       Fem artikler fra tidsskriftet "The Monist"
       1891-93.

       Introduktion og oversættelse:

       Peder Voetmann Christiansen

170/88 "OPGAVESAMLING I MATEMATIK"

       Samtlige opgaver stillet i tiden
       1974 - juni 1988

171/88 "The Dirac Equation with Light-Cone Data"

       af: Johnny Tom Ottesen