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Theoretical Investigations on the Stark-Zeeman Effect of the 2p ^{2}P$_{3/2}$-Level in ^{6}Li for Perpendicularly Crossed Fields

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Abstract. The splitting behaviour of the 2p ^{2}P$_{3/2}$ hyperfine structure levels is investigated in ^{6}Li for homogeneous crossed electric and magnetic fields (Stark-Zeeman effect). This is done by diagonalizing the perturbation matrix comprising the hyperfine interaction, the electronic and nuclear magnetic interaction and the effective electric interaction obtained by transforming the quadratic Stark effect to a first order perturbation interaction. Symmetries are used to find analytic formulae for level shifts and crossing points if only one external field is present. A reflection symmetry unbroken with all three interactions present permits the decomposition of the 12 × 12 matrix into two 6 × 6 submatrices. The structure of energy eigenvalue surfaces $\epsilon_{F,M_F}(B,E)$ of the two subsystems is found by numeric diagonalization of the perturbation matrix and is displayed in the ranges $|B| < 1$ mT, $|E| < 300$ kV/cm. The total angular momentum $F = J + I$ ($J = 3/2$, electronic angular momentum, $I = 1$, nuclear spin) and the magnetic quantum number M_F provide labels for all surfaces. All crossing points of the energy surfaces have been found. Adiabatic level transfer occurring in atoms traversing a sequence of crossed magnetic and electric fields is explained. Berry phases occur for cycles around some crossing points. Their presence or absence is explained.

PACS. 03.65.Vf Berry phase – 32.60.+i Zeeman and Stark effects – 32.80.Bx Level crossing-atoms – 3150.Gh Surface crossings

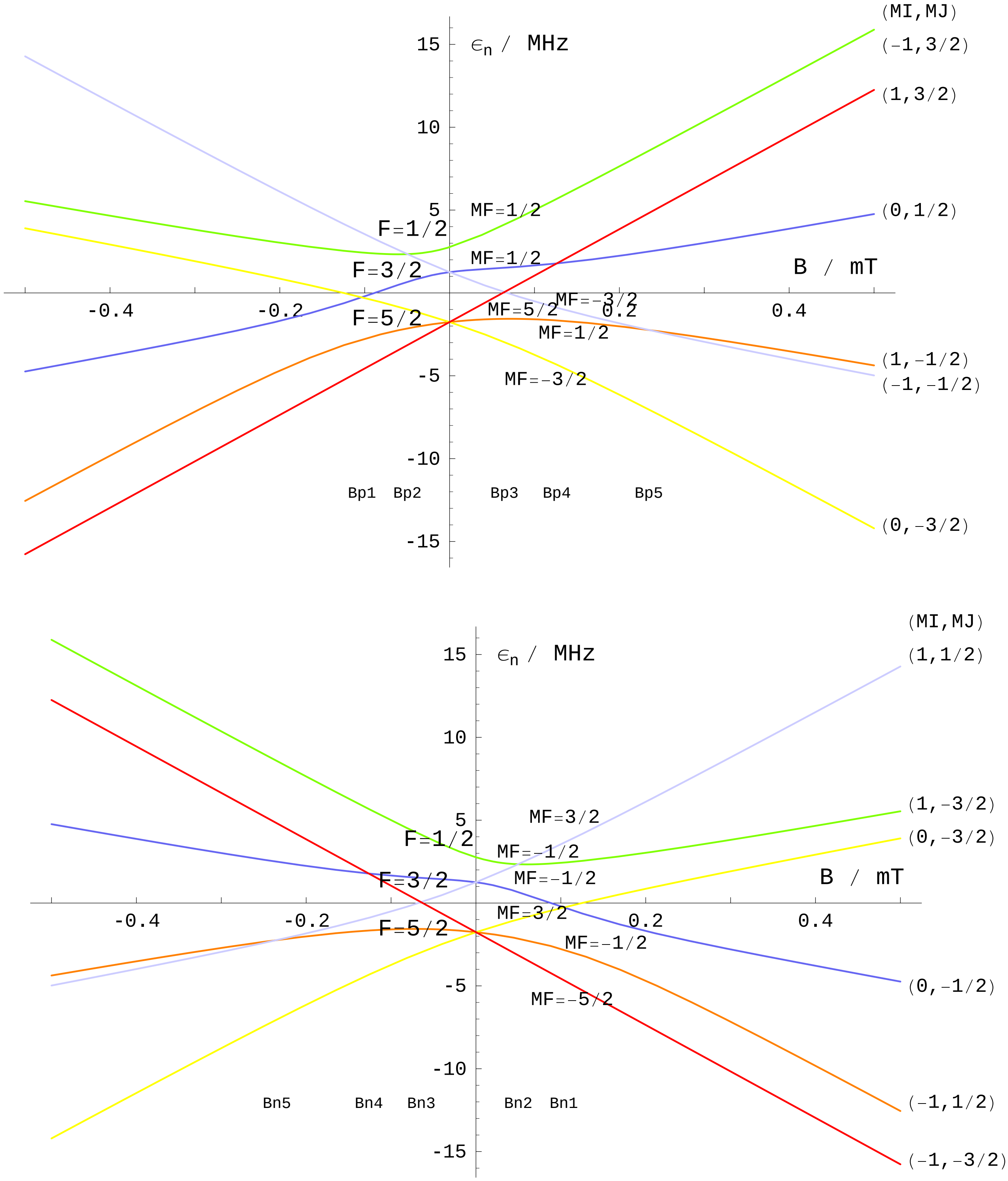

Fig. 1. Upper picture: Splitting of the 2p $^{2}P_{\frac{3}{2}}$ hyperfine energy levels ϵ_n of ^{6}Li in the positive subsystem due to the Zeeman effect. The values of the atomic parameters used are given in Table 1 of the paper. There are five crossing points, which do not show a Berry phase; their labels (Bp1,…, Bp5) are located just below each one in the line at $\epsilon'_n = -12$MHz.

Lower picture: The same for the negative system with the crossing points: (Bn1,…, Bn5)

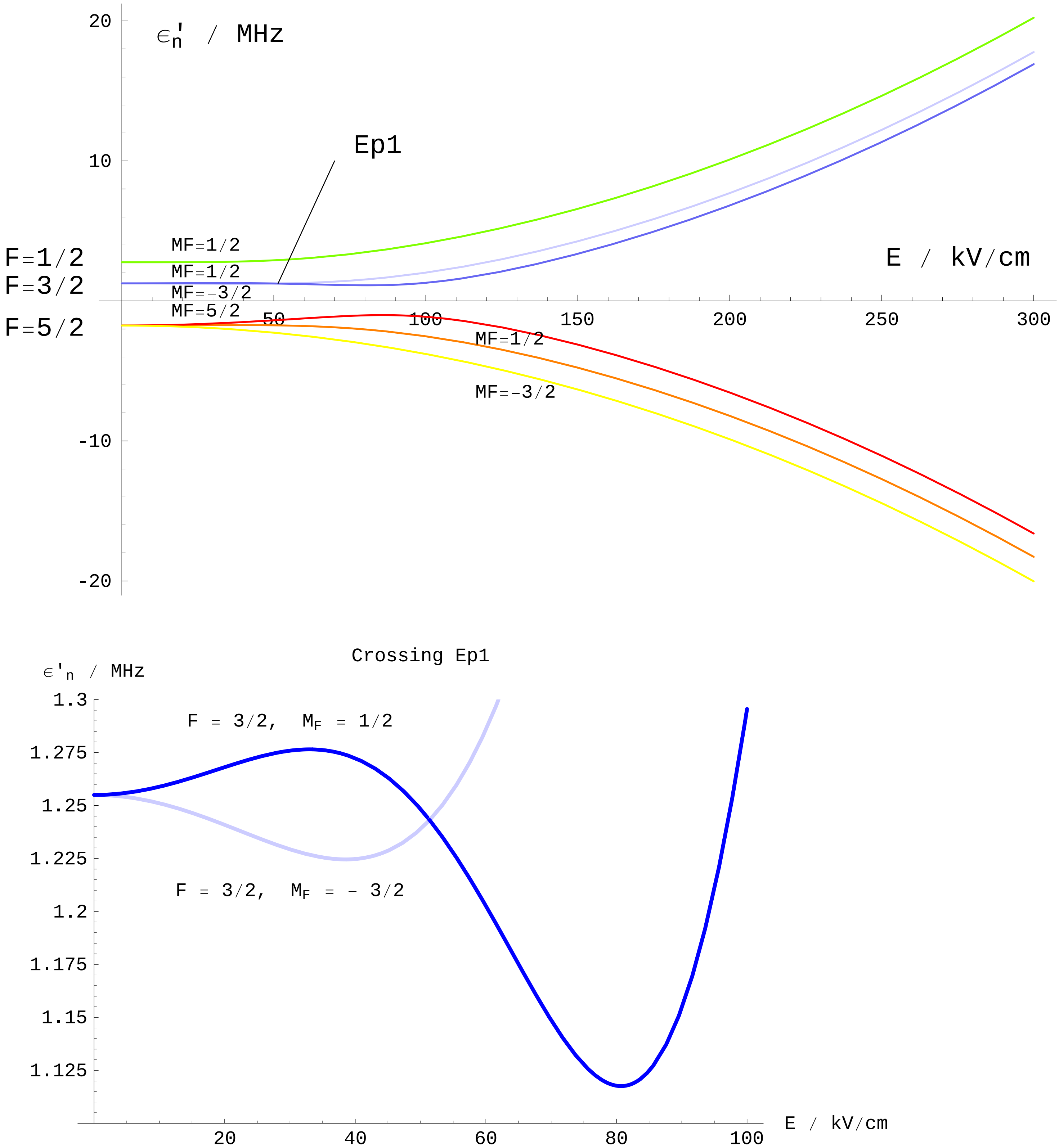

Fig. 2. Upper curve: Splitting of the 2p $^2P_{\frac{3}{2}}$ hyperfine energy levels ϵ'_n of ^{6}Li in the positive subsystem due to the Stark effect. The term proportional to the scalar polarizability α_0 was put to zero before diagonalizing the perturbation matrix. The values of the other atomic parameters are given in Table 1 of the paper. The position of the single electric crossing point Ep1 is indicated. Lower curve: Zoom on the two levels crossing at Ep1.

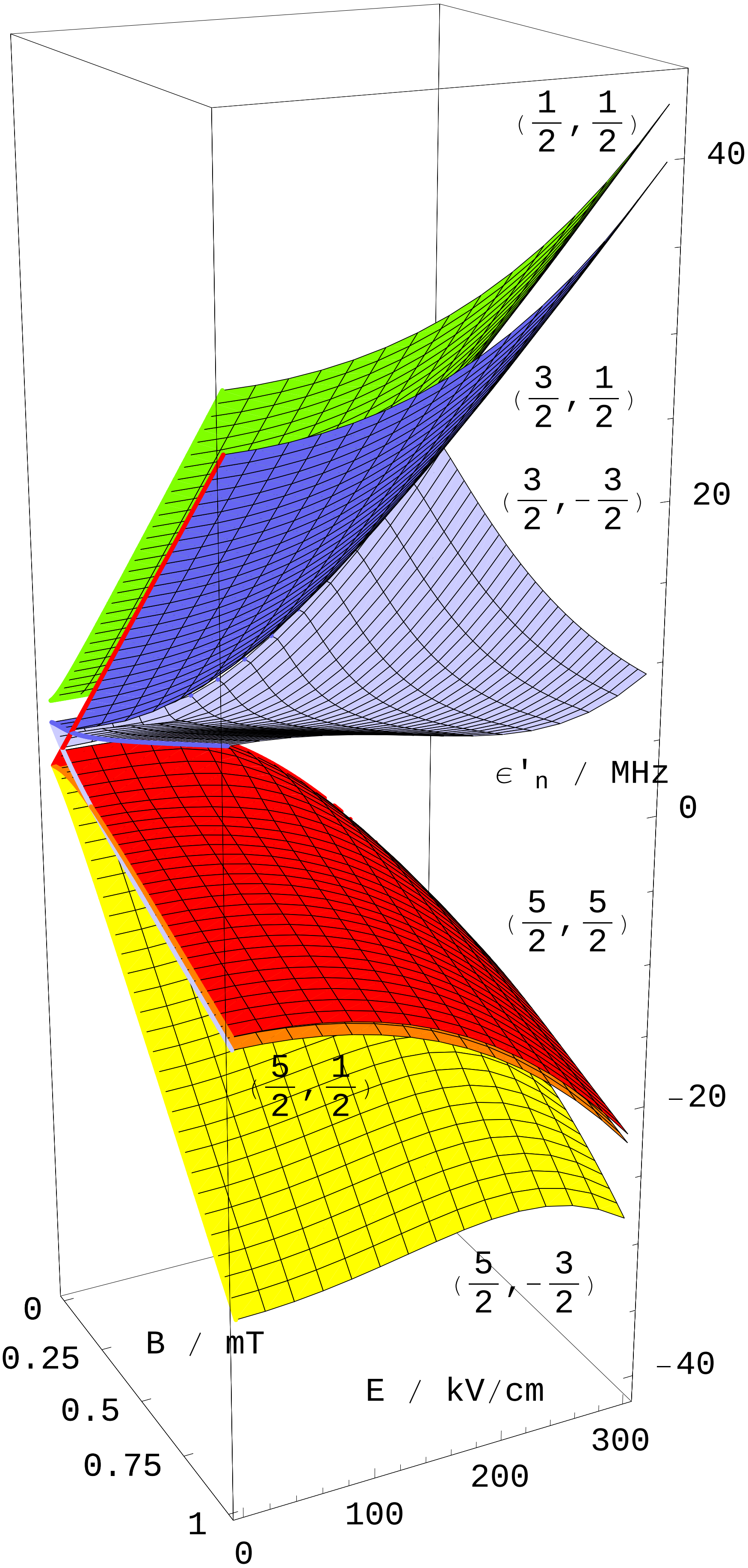

Fig. 3. Energy surfaces in the positive subsystem of ^{6}Li. The magnetic crossing points Bp1, ..., Bp3 are seen on the left.

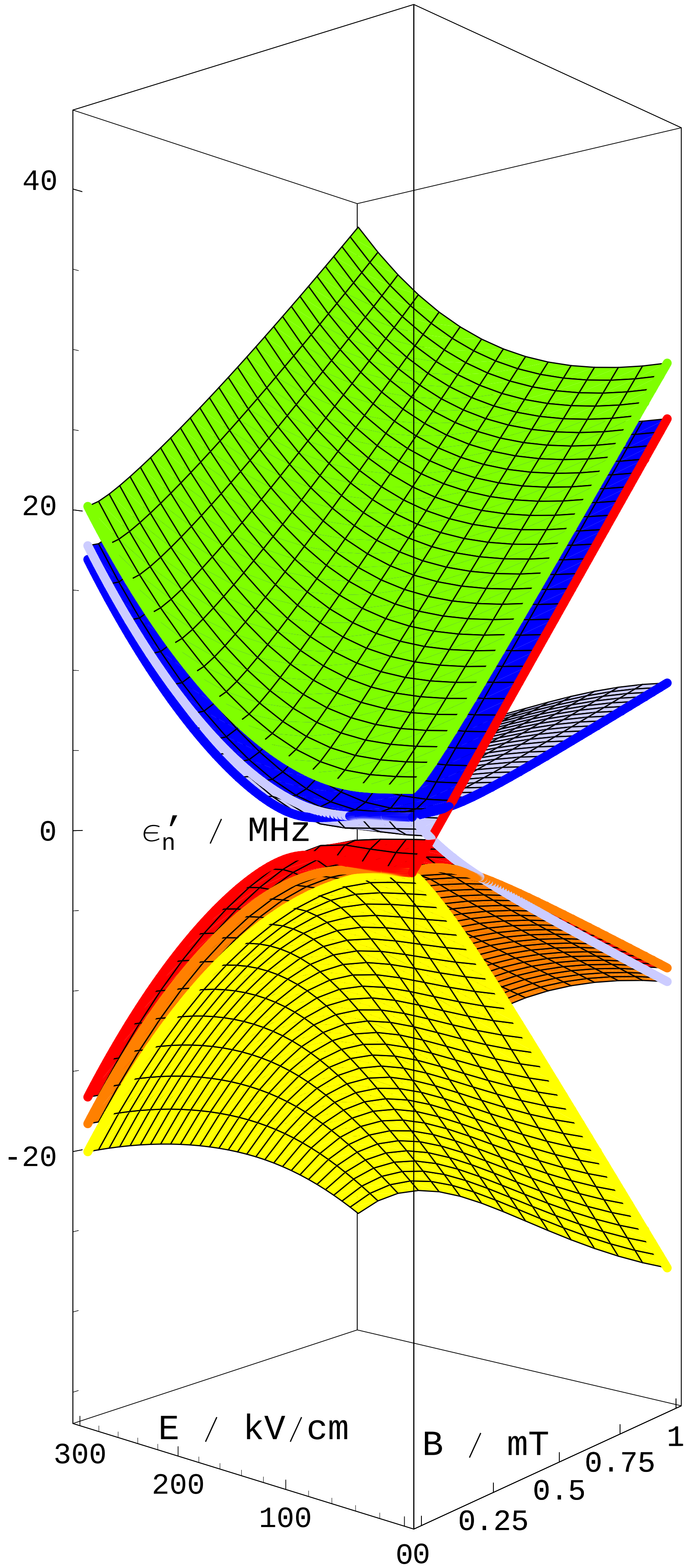

Fig. 4. Energy surfaces in the positive subsystem of ^{6}Li. The electric crossing point Ep1 is seen on the left side, the magnetic crossing points Bp1, ..., Bp3 on the right side.

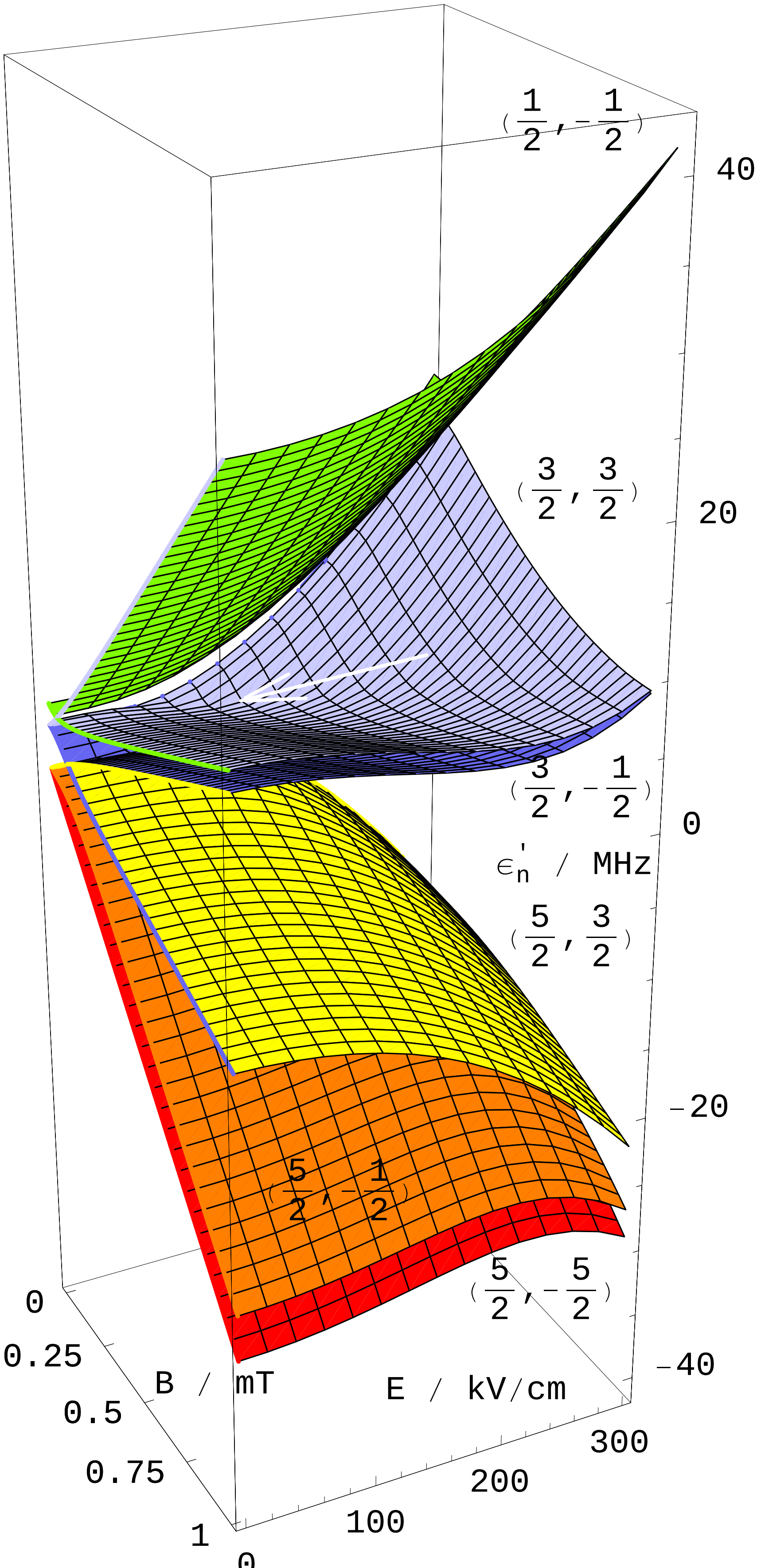

Fig. 5. Energy surfaces in the negative subsystem of ^{6}Li. The magnetic crossing points Bn1 and Bn2 are seen on the left. The arrow points to the crossing point BEn.

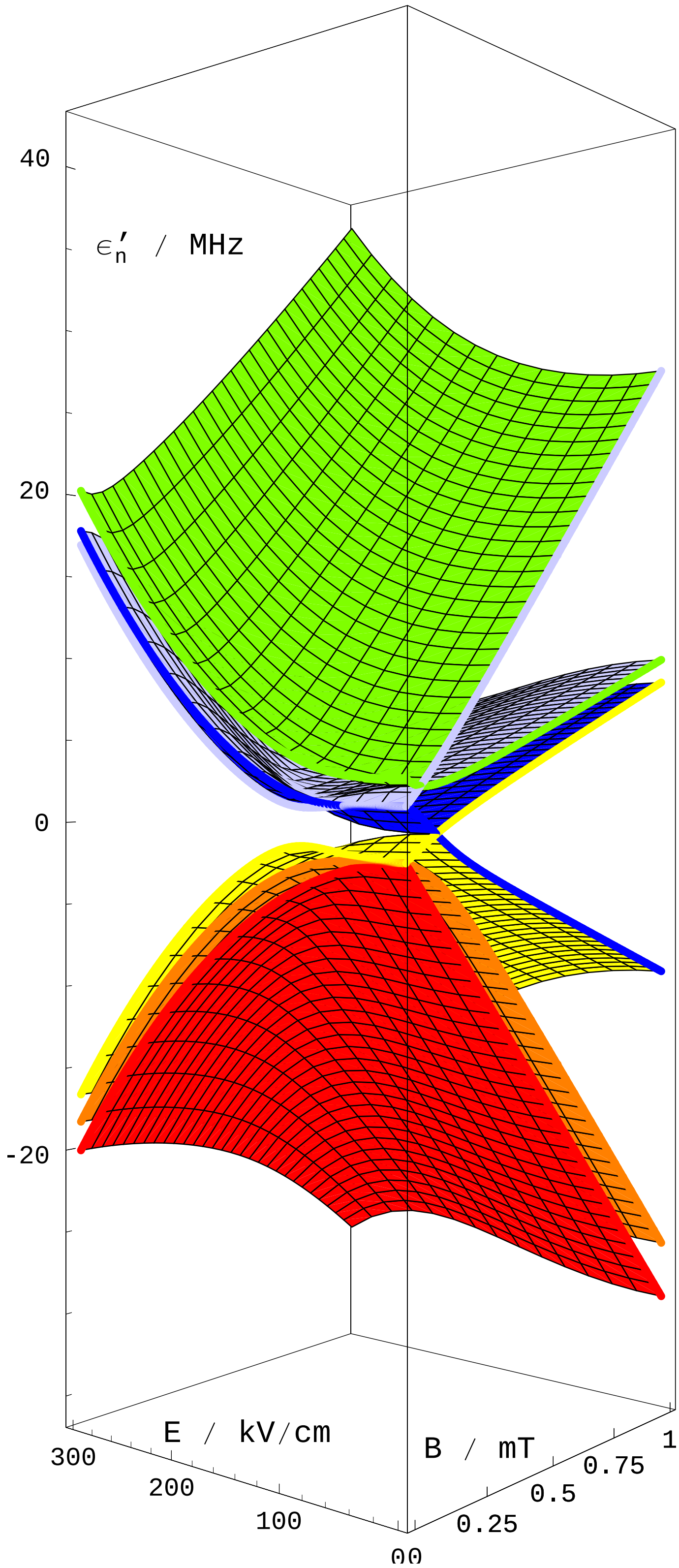

Fig. 6. Energy surfaces in the negative subsystem of ^{6}Li. The magnetic crossing points Bn1 and Bn2 are clearly visible on the right, the electric crossing point En1 on the left.

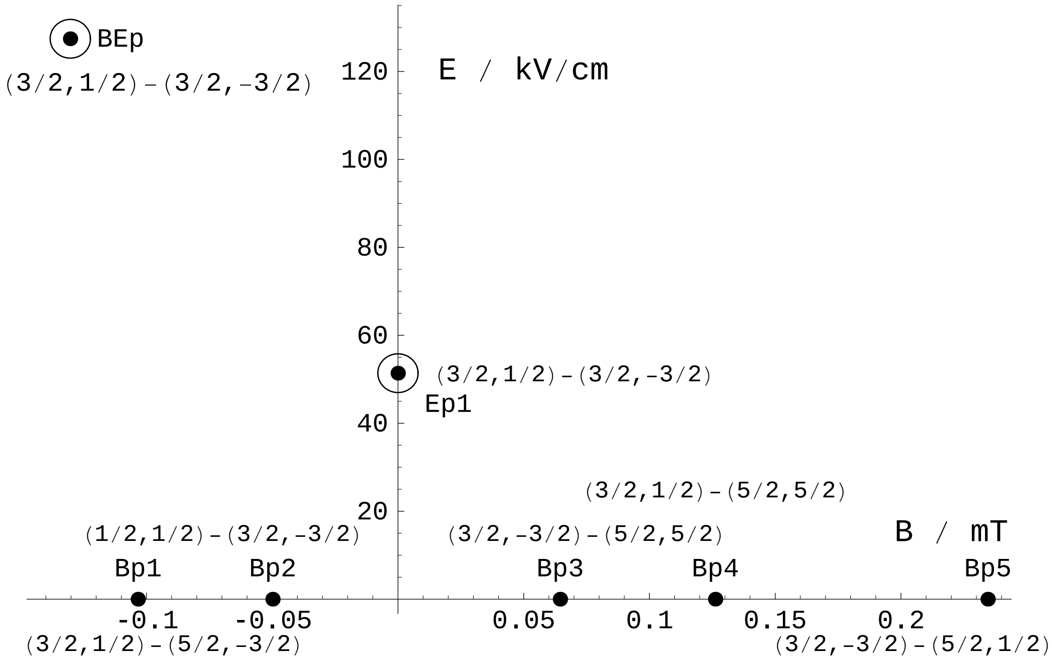

Fig. 7. Crossing diagram of the positive subsystem of ^{6}Li. The crossing points showing a Berry phase are marked by circles. The labels (F, M_F) of the two crossing levels are given at the corresponding crossing point.

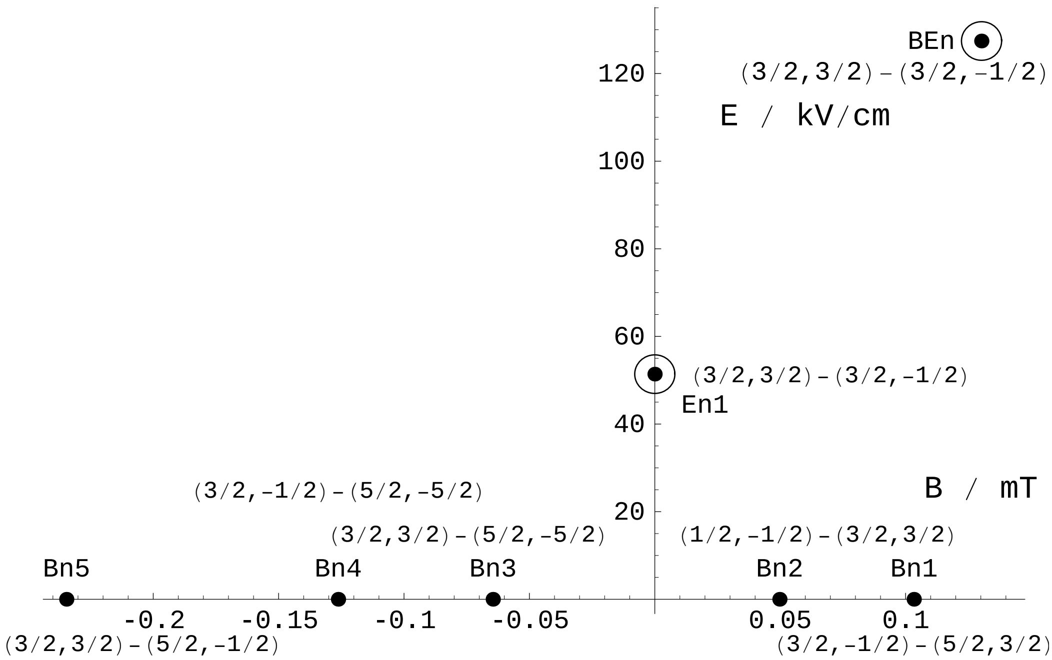

Fig. 8. Crossing diagram of the negative subsystem of ^{6}Li. The crossing points showing a Berry phase are marked by circles. The labels (F, M_F) of the two crossing levels are given at the corresponding crossing point.

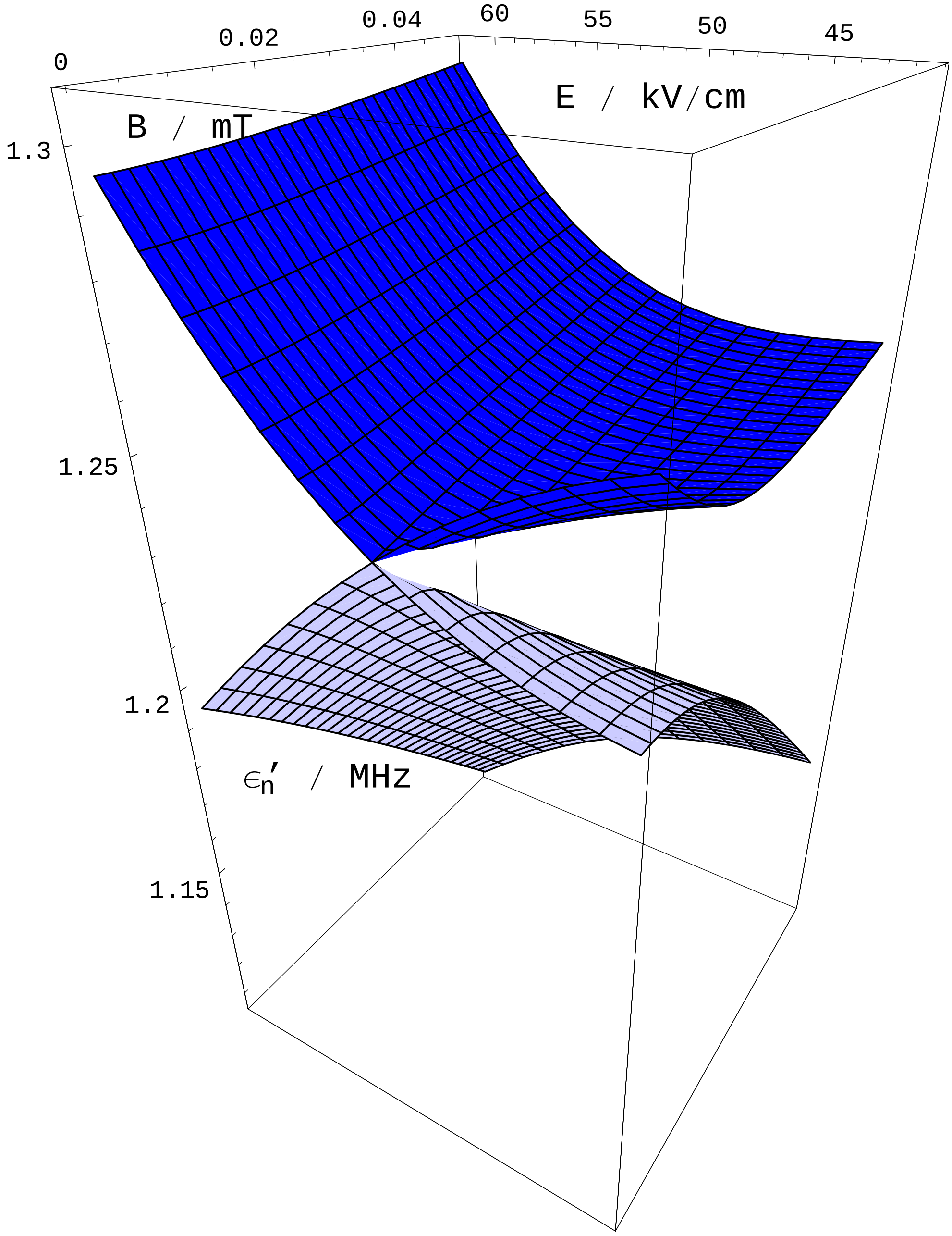

Fig. 9. Energy surface in the neighbourhood of the crossing point $Ep1$, which shows a Berry phase. ϵ_n' is linear in both B and E. The resulting bicone is cut in half in the plane $B = 0$.

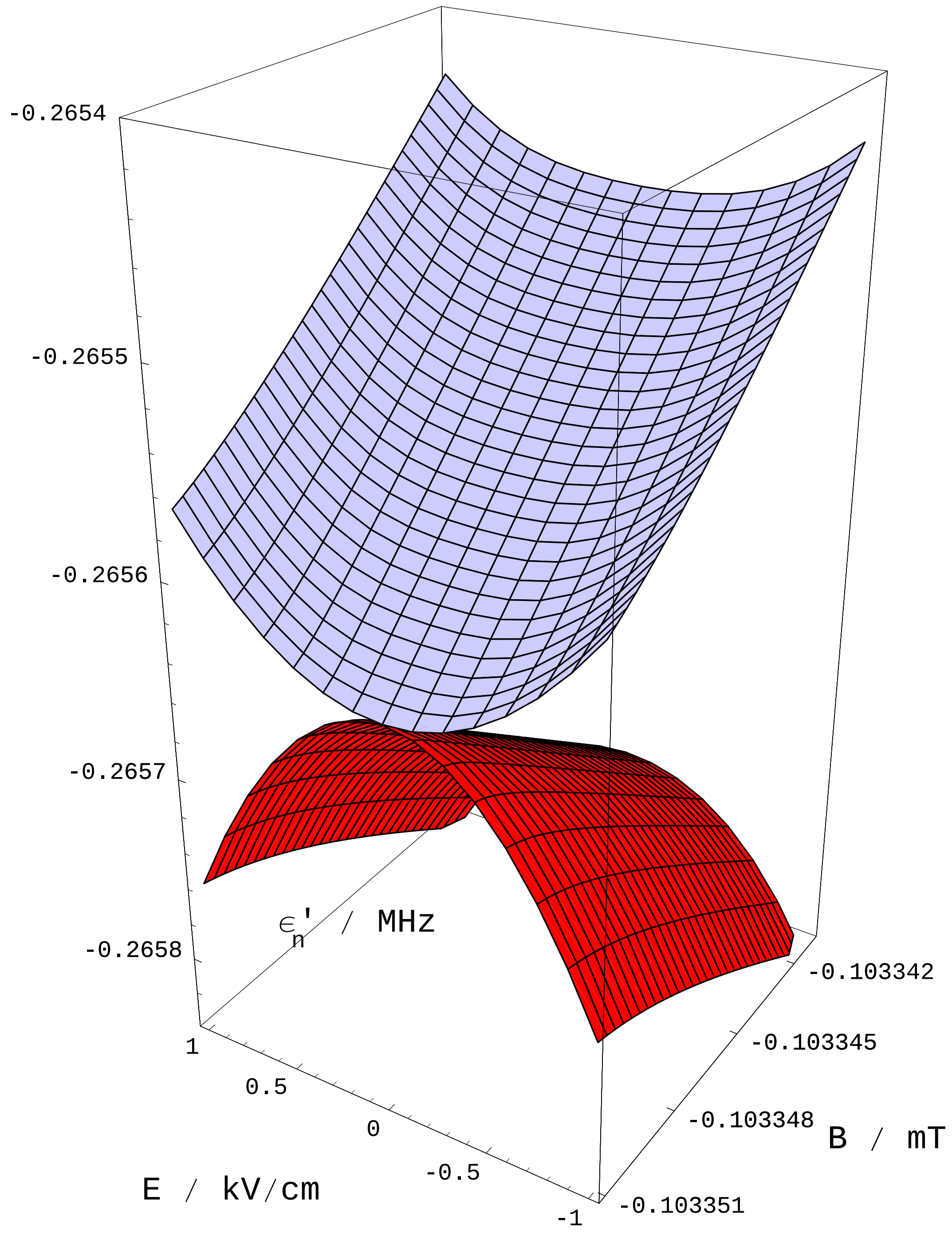

Fig. 10. Energy surfaces in the neighbourhood of the crossing point $Bp1$, which does not show a Berry phase. ϵ_n' is linear in B and quadratic in E. The resulting surfaces are no longer conic sections. They are cut along the plane $B = B_{Bp1} = 0.1033508$ mT.

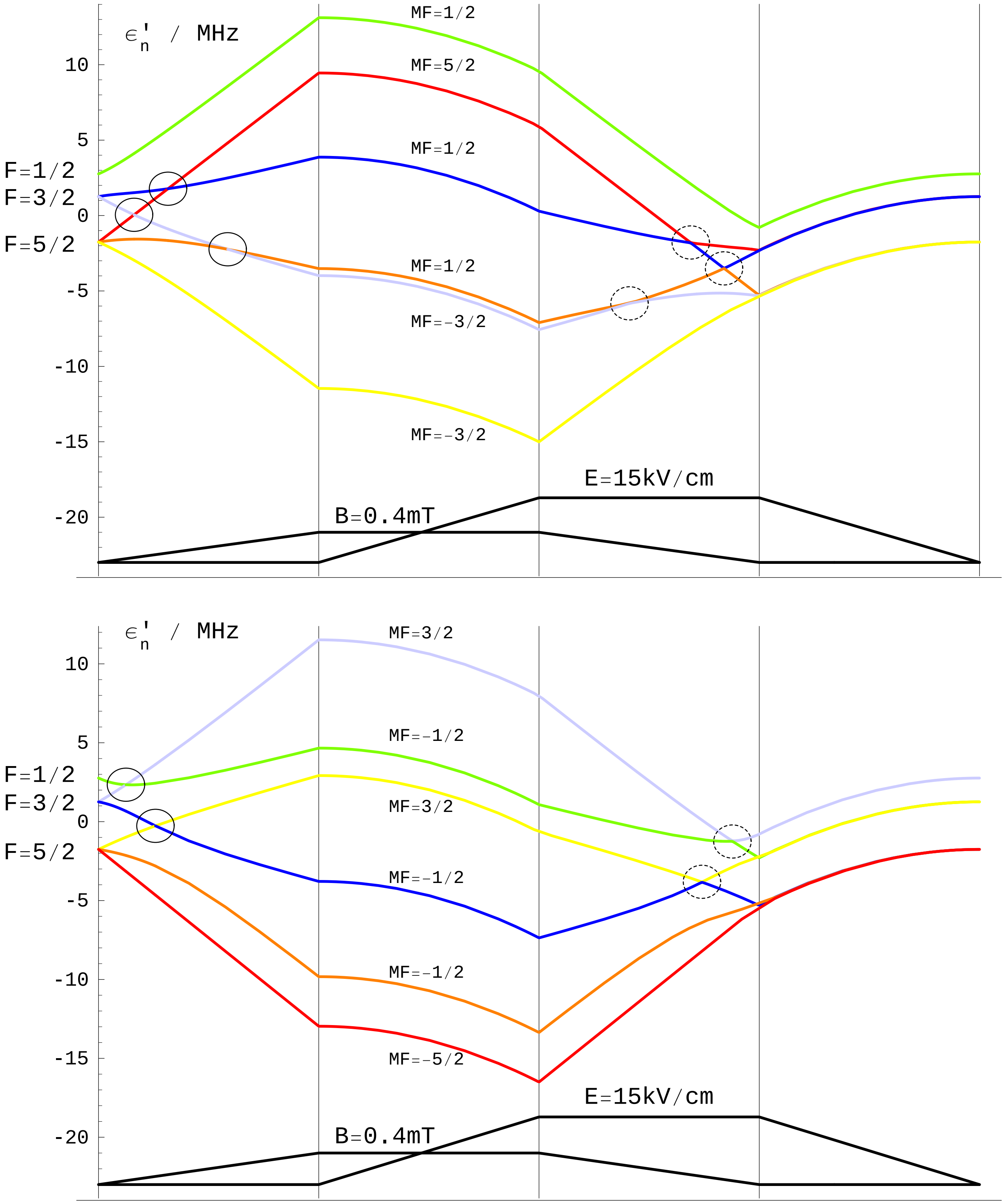

Fig. 11. Upper picture: Sample field cycle of the electromagnetic field with the corresponding splitting of the 2p $^2P_{3/2}$ hyperfine levels of ^{6}Li in the positive subsystem. For lack of space, the magnetic quantum numbers are written in the second interval; they are only valid in the first interval, where there is only a magnetic field present. The total angular momentum numbers F as well as the corresponding magnetic number M_F are assigned to the level and curve by analytic continuation, i.e. according to the overlap of the eigenvectors found by in- or decrementing the field values in sufficiently small steps.

Lower picture: The same for the negative system.

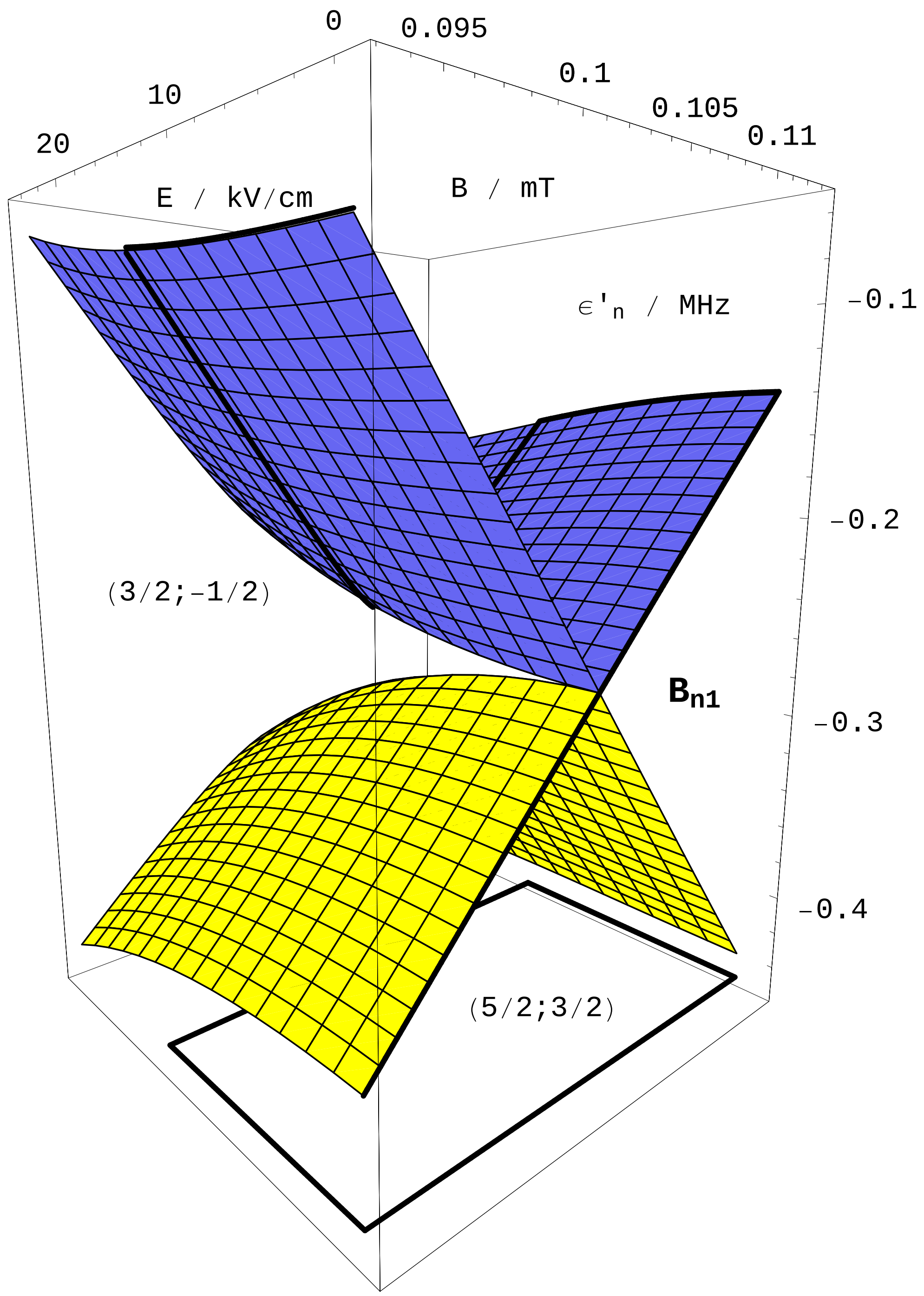

Fig. 12. View of the magnetic crossing point Bn1. The black rectangle at the bottom shows the cycle of fields in the B, E-plane. The black curve gives the corresponding phase curve of the atom on the two parts of the energy surfaces. It starts at $B = 0.093$ mT, $E = 0$ in the surface labelled ($F = 5/2;\ M_F = 3/2$) and ends at the point $B = 0.093$ mT, $E = 0$ on the upper surface with labels ($F = 3/2;\ M_F = -1/2$).