UCRL-20588
c.2

RECEIVED
LAWRENCE
RADIATION LABORATORY

JUN 9 1971

LIBRARY AND
DOCUMENTS SECTION

University of California

Ernest O. Lawrence Radiation Laboratory

CORRELATION BETWEEN BACKWARD STIMULATED RAMAN PULSE AND MOVING FOCUS IN LIQUIDS

M. M. T. Loy and Y. R. Shen

May 1971

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

Berkeley, California

UCRL-20588
c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UNIVERSITY OF CALIFORNIA

Lawrence Berkeley Laboratory
Berkeley, California

August 10, 1971

ERRATA

TO: All recipients of UCRL-20588

FROM: Technical Information Division

Subject: UCRL-20588, "Correlation Between Backward Stimulated Raman Pulse and Moving Focus in Liquids", M. M. T. Loy and Y. R. Shen, May 1971

Please make the following correction on subject report:

Page 7, add the following figure :

Fig. 3. Oscilloscope traces of the input laser pulses (left traces; 10 nsec/div.) and the corresponding filament and backward Raman pulses (right traces; 2 nsec/div.). Both the filament pulses (the lead ones) and the Raman pulses have pulse durations less than 0.1 nsec. From the time separation between the two pulses, we can deduce the spatial separation d (see the text). The input peak power was below the self-focusing threshold in (a) and above the self-focusing threshold in (b) and (c) for the same cell length. It is seen in (b) and (c) that the pulse separation increases as the input power increases.

Page 10, add Figure 3.

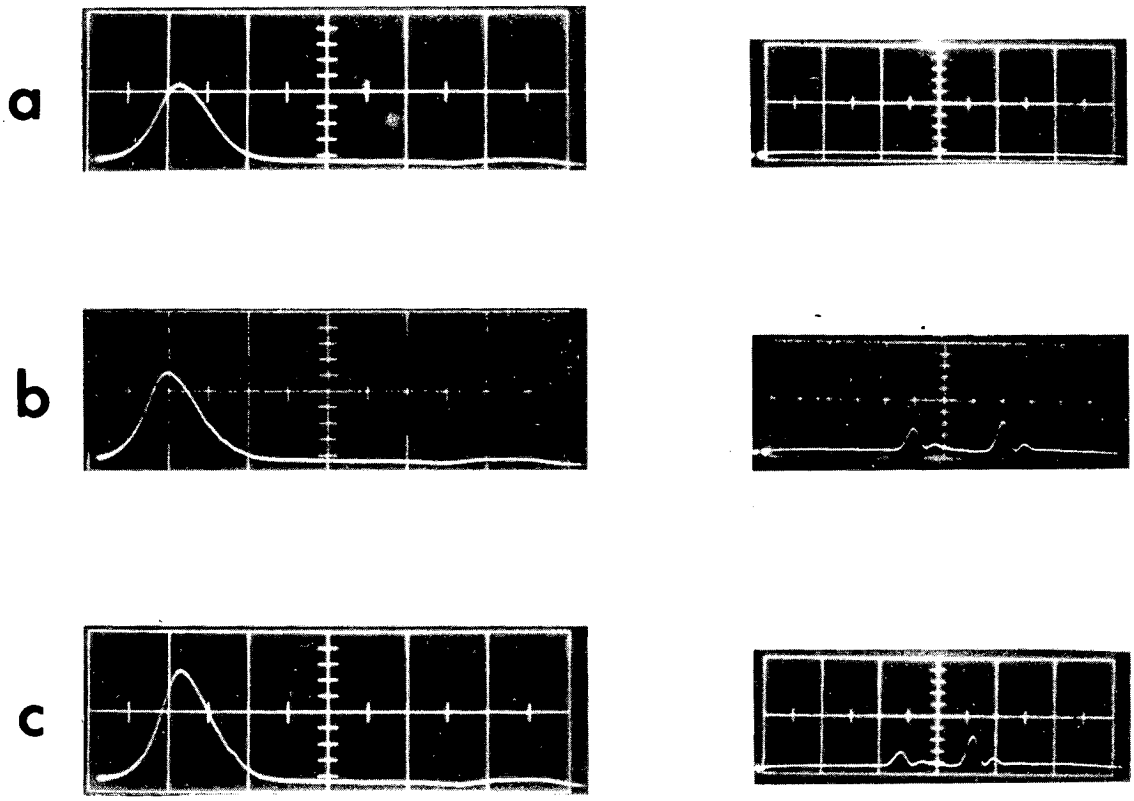
9/2/71

FIGURE CAPTIONS

Fig. 1. U curve describing the position of the focal spot as a function of time resulting from self-focusing of a Q-switched laser pulse. The wavefront of the backward Raman pulse originates from the point A and propagates along the dot-dashed line with light velocity c/n. The distance d is the spatial separation between the backward Raman pulse and the "filament" pulse at the time when the latter leaves the cell.

Fig. 2. Pulse separation d as a function of peak power of input laser pulse for four different cell lengths. The solid curves are obtained from the experimentally determined U curves using the moving focus model. The discrete data points are obtained from direct time correlation measurements without referring to any model.

Fig. 3. Oscilloscope traces of the input laser pulses (left traces; 10 nsec/div.) and the corresponding filament and backward Raman pulses (right traces; 2 nsec/div.). Both the filament pulses (the lead ones) and the Raman pulses have pulse durations less than 0.1 nsec. From the time separation between the two pulses, we can deduce the spatial separation d (see the text). The input peak power was below the self-focusing threshold in (a) and above the self-focusing threshold in (b) and (c) for the same cell length. It is seen in (b) and (c) that the pulse separation increases as the input power increases.



XBB 718-3450

Fig. 3

Submitted to Applied Physics Letters

UCRL-20588
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

CORRELATION BETWEEN BACKWARD STIMULATED RAMAN PULSE AND MOVING FOCUS IN LIQUIDS

M. M. T. Loy and Y. R. Shen

May 1971

37

Correlation Between Backward Stimulated Raman Pulse and Moving Focus in Liquids

M. M. T. Loy and Y. R. Shen

Department of Physics, University of California
and
Inorganic Materials Research Division,
Lawrence Radiation Laboratory,
Berkeley, California 94720

ABSTRACT

We have studied the correlation between backward stimulated Raman pulse and small-scale "filament" induced by Q-switched laser pulse in Kerr liquids. We show that the "filament" is the result of a moving focus and that the backward Raman pulse is initiated by the moving focus inside the liquid cell.

In studying stimulated Raman scattering in Kerr liquids with a Q-switched laser, Maier et al.[1] have demonstrated that the backward Raman radiation often appears as an intense ultrashort pulse. They assume the Raman radiation is initiated from the "filament" at the end of the cell and show that the ultrashort Raman pulse results from continuous amplification of the leading edge of the pulse through interaction with the incoming fresh laser beam.[1] Recently, we have proved[2] that, with Q-switched pulses, the so-called "filament"[3] is simply the result of a moving focus.[4] We have also been able to correlate both forward and backward Raman pulses with the moving focal spot.[2,5] In this letter we show, from results of time correlation measurements, that the backward Raman pulse can often be initiated from the moving focus well inside the cell. The experimental results agree quantitatively with predictions from the moving focus model and therefore can also be taken as a direct confirmation of the moving focus model.

To illustrate the correlation between backward Raman radiation and the moving focus, we show, in Fig. 1, the U curve describing the position of the focal spot inside the cell as a function of time.[2,6] This U curve is obtained from the equation for the self-focusing distance[7]

$$z_f(t) = K/[P^{1/2}(t - z_f n/c) - P_{cr}^{1/2}] \qquad (1)$$

where P(t) is the power of the input laser pulse, and K and P_{cr} are

parameters determined by the beam characteristics and liquid properties.[7] The extremely high laser intensity in the focal region initiates stimulated Raman scattering readily. Consequently, we would expect to see Raman radiation continuously initiated from the moving focal spot. However, for the backward Raman radiation, it is clear from Fig. 1 that the leading edge is initiated from the region around A where the slope of the curve is -c/n. This leading edge of the Raman pulse propagating backward along the dot-dashed line intercepts the incoming fresh laser beam before the laser beam is self-focused. Then, at the expense of the laser beam, it gets amplified into an intense ultrashort pulse, as has been observed.[1] On the other hand, the highly depleted laser beam is no longer strong enough to self-focus. As a result, the focal spot moving on the lower branch of the U curve gets terminated not too far away from the point A.

We now consider the upper branch of the U curve (above A). Here, self-focusing is not affected in any significant way by stimulated scattering since the self-focused beam is not intercepted by the backward Raman radiation. In a sufficiently long cell, the focal spot actually appears moving forward towards the end of the cell with a velocity faster than light velocity.[2] If we arrange the detector to collect only light emitted from the focal spot appearing within the last 1 cm of the cell, we should expect to see a pulse shorter than 0.1 nsec. As seen from Fig. 1, at the time when this short pulse just leaves the end of the cell, ℓ, it is at a distance d apart from the backward Raman pulse.

Thus, using the moving focus model, we can find d from a given U curve for a given cell length. The U curve is constructed from Eq. (1), where the quantities P(t), P_{cr} and K can all be obtained experimentally.[2] In our experiments, we used a single-mode ruby laser with a beam diameter of 300 μm, a pulse width of 8 nsec, and maximum peak power of about 200 kW. Self-focusing of the beam in Kerr liquids consistently led to a single "filament." We measured $K/P_{cr}^{1/2}$ using the method of Wang,[8] and found in toluene $K/P_{cr}^{1/2} = 2.8$ cm. We then monitored the input laser pulse by an ITT F4018 fast detector in connection with a Tektronix 519 oscilloscope. The calibrated oscilloscope trace yielded the function $P(t)/P_{cr}$, which in turn gives the corresponding U curve. We were thus able to find the value d as a function of the peak power of the input laser pulse at a given cell length. The results are given by the solid curves in Fig. 2 for four different cell lengths.

On the other hand, we can measure d directly without referring to any model. This was done by recording simultaneously the "filament" pulse (from the focal spot at the end of the cell) and the backward Raman pulse on the 519 oscilloscope and measuring the time separation Δt between the two pulses. From the known optical paths of the two pulses, we can easily obtain d from the measured Δt. For each shot, we also monitored simultaneously the input pulse on another 519 oscilloscope. The results are shown in Fig. 2 as discrete data points. They agree very well with the solid curves.

The good quantitative agreement between the measured d and that calculated from the U curve using the moving focus model leads to the following conclusions. First, the backward Raman pulse is indeed

initiated from the point A (Fig. 1) inside the cell, unless the cell length is less than z_A. In the latter case, the pulse is initiated at the end of the cell and accordingly, d is zero.[9] Second, the "filament" is in fact the result of moving focal spot, at least for the case of Q-switched pulses. Third, the focal-spot movement is quite accurately described by Eq. (1). In particular, since the experiment involves the upper branch of the U curve, it shows that the focal spot can indeed move forward with a velocity faster than light velocity.[2]

ACKNOWLEDGEMENTS

This work was performed under the auspices of the U. S. Atomic Energy Commission.

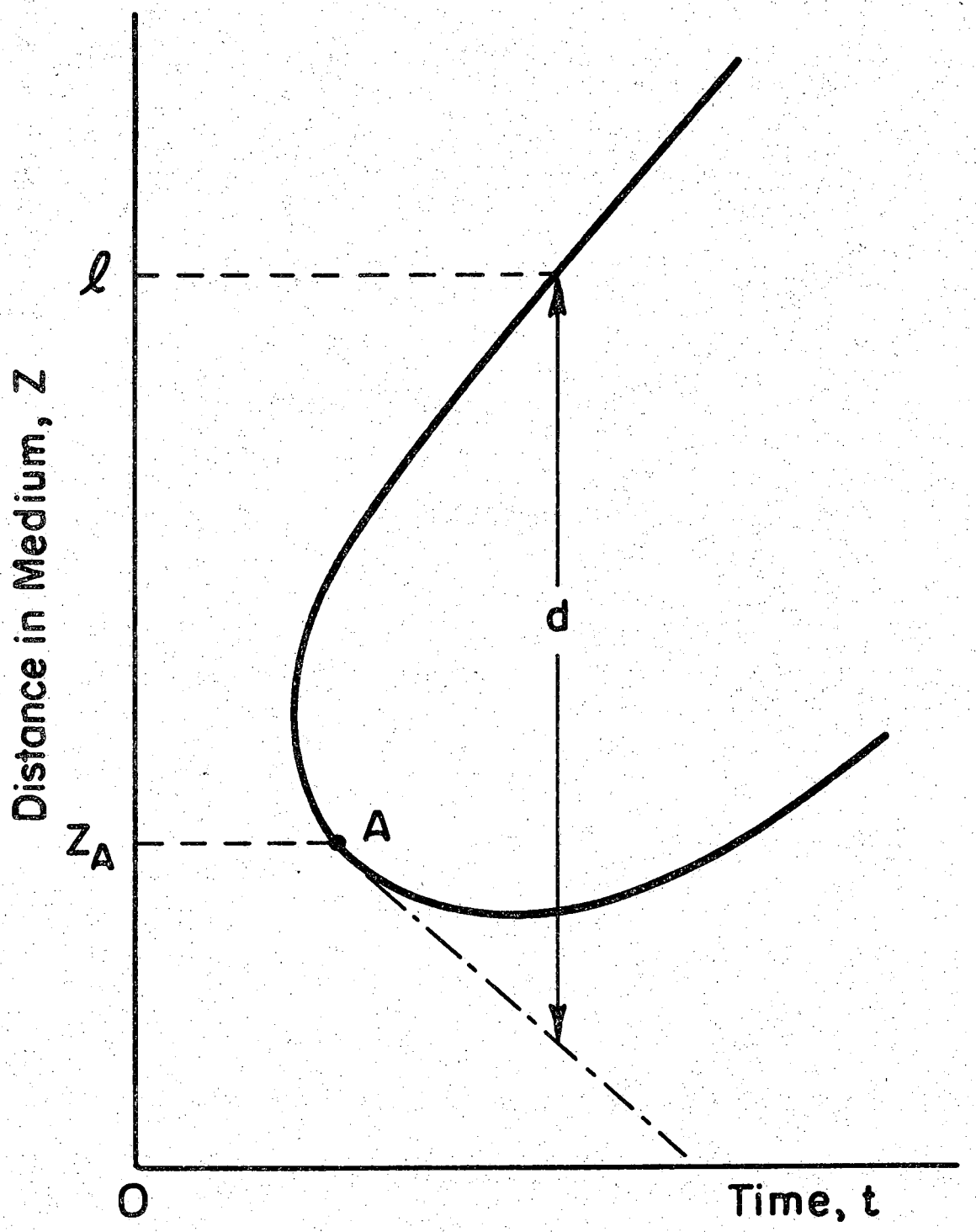
REFERENCES

1. M. Maier, W. Kaiser, and J. A. Giordmaine, Phys. Rev. Letters 17, 1275 (1966); Phys. Rev. 177, 580 (1969).
2. M. M. T. Loy and Y. R. Shen, Phys. Rev. Letters 22, 994 (1969); 25, 1333 (1970).
3. R. Y. Chiao, M. A. Johnson, S. Krimsky, H. A. Smith, C. H. Townes, and E. Garmire, IEEE J. Quantum Electron. QE-2, 467 (1966).
4. V. N. Lugovoi and A. M. Prokhorov, Zh. Eksperim. i Teor. Fiz.-Pis'ma Redakt. 7, 153 (1968) [Translation: JETP Letters 7, 117 (1968)].
5. Detailed experimental results and interpretation will be published elsewhere.
6. T. K. Gustafson and J. P. Taran, IEEE J. Quantum Electron. QE-5, 381 (1970); A. A. Abramov, V. N. Lugovoi, and A. M. Prokhorov, Zh. Eksperim. i Teor. Fiz.-Pis'ma Redakt. 9, 675 (1969) [English Trans: JETP Lett. 9, 419 (1969)].
7. P. L. Kelley, Phys. Rev. Letters 15, 1005 (1965).
8. C. C. Wang, Phys. Rev. Letters 16, 344 (1966).
9. We notice that in Ref. 1, the laser pulse had a pulse duration of 15 nsec, a beam diameter of 2mm, and a peak power of 1 Mwatts. Then, in a 30 cm CS_2 cell, the focal spot should first appear at the end of the cell and move backward, and the corresponding backward Raman pulse should actually originate at the end of the cell as the authors correctly assumed.

FIGURE CAPTIONS

Fig. 1. U curve describing the position of the focal spot as a function of time resulting from self-focusing of a Q-switched laser pulse. The wavefront of the backward Raman pulse originates from the point A and propagates along the dot-dashed line with light velocity c/n. The distance d is the spatial separation between the backward Raman pulse and the "filament" pulse at the time when the latter leaves the cell.

Fig. 2. Pulse separation d as a function of peak power of input laser pulse for four different cell lengths. The solid curves are obtained from the experimentally determined U curves using the moving focus model. The discrete data points are obtained from direct time correlation measurements without referring to any model.



XBL715-6752

Fig. 1

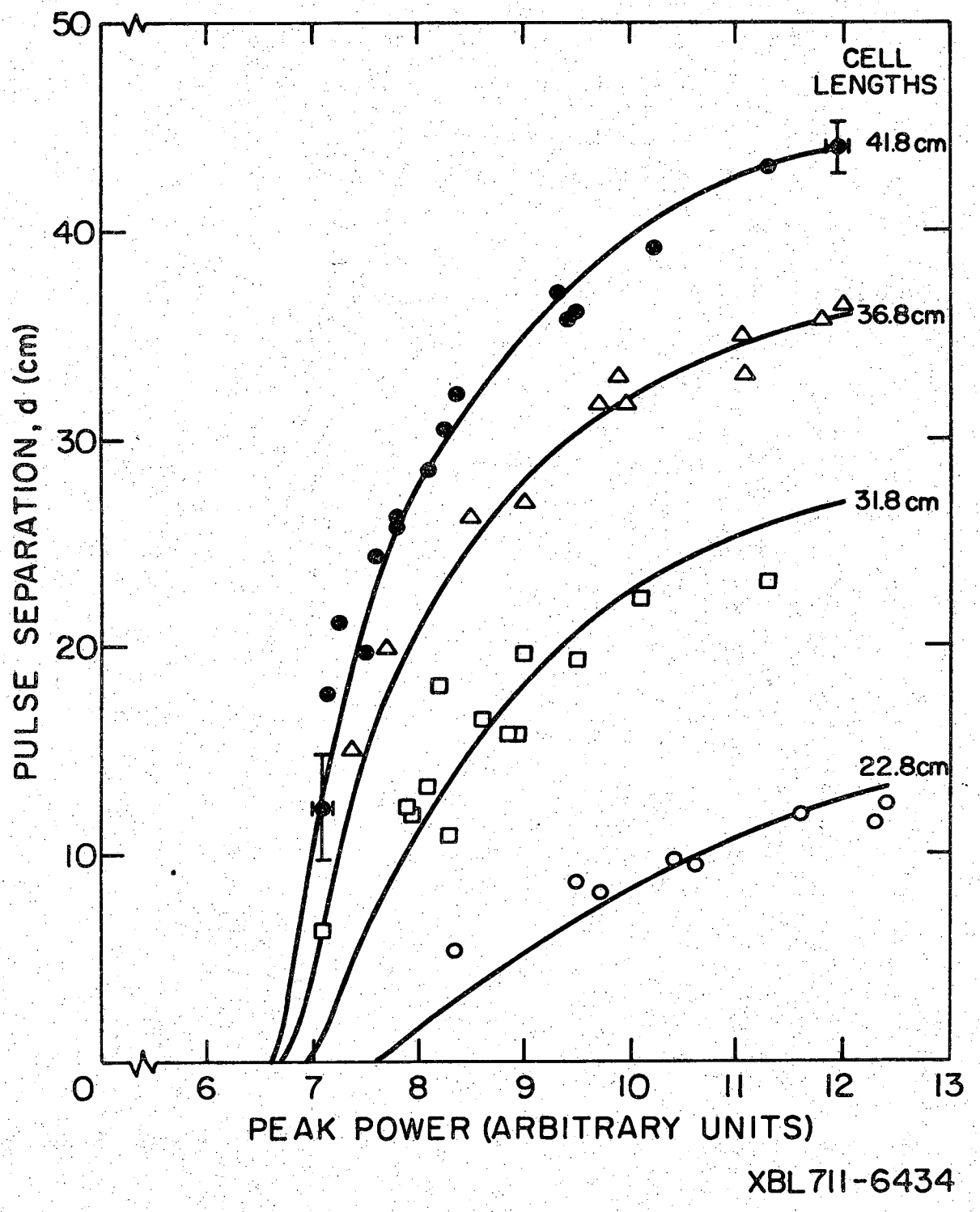

CELL LENGTHS
41.8 cm
36.8cm
31.8 cm
22.8cm
PULSE SEPARATION, d (cm)
PEAK POWER (ARBITRARY UNITS)
0
10
20
30
40
50
6
7
8
9
10
11
12
13
XBL711-6434

Fig. 2