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APPENDIX C

NSF 93-[illegible]

National Science Foundation
Small Business Innovation Research Program

PROJECT SUMMARY

NSF AWARD NO.

NAME OF FIRM
Protein Solutions, Inc.

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390 Wakara Way
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PRINCIPAL INVESTIGATORS (NAME AND TITLE)
Li Feng, Research Engineer

TITLE OF PROJECT
The Labless Lab: Polymer Materials

TOPIC TITLE
Education and Human Resources

TOPIC NUMBER
25

TECHNICAL ABSTRACT (LIMIT TO 200 WORDS)

(A)

A very large number of science and engineering courses taught in colleges and universities today do not involve laboratories. Although good instructors incorporate class demonstrations, hands on homework, and various teaching aids, including computer simulations, the fact is that students in such courses often accept key concepts and experimental results without discovering them for themselves. The only partial solution to this problem has been increasing use of class demonstrations and computer simulations.

We propose the development of a completely self contained polymer materials laboratory which, although packaged like a textbook, will contain within it all of the materials, equipment, and information needed to directly discover and experience key concepts related to polymer materials. We expect that such a Labless Lab Book will be widely adopted as a supplement to the more conventional polymer science and engineering textbooks, particularly in those courses which do not have a laboratory section or component.

We expect to eventually expand this approach to a wide variety of science and engineering courses. It is appropriate to begin with polymer materials, however, because polymeric materials are so readily available for a wide variety of applications and because they exhibit a range of phenomena which are very easy to observe, experience, and discover.

KEY WORDS TO IDENTIFY RESEARCH OR TECHNOLOGY (8 MAXIMUM)

Science Kit, laboratory supplies, laboratory equipment, hands on, knowledge representation, advanced materials

POTENTIAL COMMERCIAL APPLICATIONS OF THE RESEARCH

Manufacture and sales of a Lab Book/Kit for adoption and use by colleges and universities for polymer materials, materials science, and chemistry courses.

D. OPPORTUNITY IDENTIFICATION AND SIGNIFICANCE:

(C)

Undergraduate students in many science and engineering courses in the United States have little or no laboratory experience in such courses. The labless science and engineering course has become a very common feature in higher education. Although outstanding instructors attempt to overcome this deficiency with the use of classroom demonstrations, discovery based homework assignments, class projects, and computer simulations, many instructors may not have the time or inclination to utilize these tools, particularly in relatively large lecture environments. Labs are also not generally available for correspondence, distance learning, or TV/video delivered courses. ~~We feel~~ there is a need for small, inexpensive, completely self contained laboratories which can be supplements to existing textbooks.

(B)

This concept does not only apply to polymer materials, but indeed applies to all such labless technical courses. We feel strongly that many complex concepts can be observed and assimilated by experimentation with properly designed materials. We propose the development of materials and specimens designed specifically for teaching purposes.

Nearly 3,000 colleges and universities in the United States teach a wide variety of science and technical courses. Virtually every one of them teaches several years of chemistry, physics, and biology. Freshman textbooks in Chemistry, for example, usually include a chapter on polymers and biopolymers. Physics and Biology texts often include chapters on the solid state and on biopolymers, respectively.

(D)

The several hundred undergraduate engineering programs in the country nearly all teach a course in materials science, with a significant polymer component, and many of them teach a separate course in polymer materials. There are of the order of 40,000 introductory materials science texts sold annually in the U.S. and Canada (1-2). In addition, advanced high school chemistry or physics courses often include a significant polymer materials component. The National Science Teachers Association has a high school supplement text which is very popular with high school teachers throughout the country.

Although many of these texts come with instructions for experiments and demonstrations, in reality these are rarely done because of the difficulty in obtaining the materials in a timely and inexpensive fashion.

(E)

The Exploratorium, an interactive, hands on science museum in San Francisco, and Klutz Press in Palo Alto, California, recently teamed up to produce a volume called The Explorabook, in which a range of hands on, discovery based experiments were incorporated into a small inexpensive book. ~~We urge the key reviewers of this proposal to obtain a copy of The Explorabook, available at their local science museum or planetarium giftshop, science project store, or even in toy stores which contain a science kit section.~~

The Explorabook is the largest selling children's science book in the United States today. It demonstrates the need for challenging scientific materials by the general public. That need is also present in higher education. The recent Project 2061 report is appropriate here (29):

> *"For teachers to be able to bring all students to the level of understanding and skill proposed in this report, they will need a new*

generation of books and other instructional tools...Textbooks and other teaching materials in current use are - to put it starkly - simply not up to the job."

E. BACKGROUND, APPROACH, AND BENEFITS:

1. Background and Proposed Research:

Plastic and polymeric materials are ubiquitous in modern society. A significant fraction of all chemists and engineers work in polymer related industries or utilize polymers in scientific and engineering activities.

Polymeric materials are also somewhat controversial because of the environmental concern with solid waste disposal and biodegradation. Interest in these topics has grown enormously in recent years.

Polymers are being widely used in basic science education because of their unique properties and their ready availability. The National Science Teachers Association often includes articles related to polymers in each of its 4 publications dealing with science education - at all age levels, from K-16.

F

Polymeric materials are unique because of their polymeric nature. Large molecular weight molecules behave, in general, very differently from low molecular weight molecules and conventional molecular or atomic solids. Many of the rules of thumb learned in elementary physics and chemistry appear to not apply in the case of polymeric materials.

Most students come into polymer courses with various concepts and preconceptions which lead them to conclude that the behavior and properties of polymers are counter intuitive. It is therefore important that they fully discover and observe the properties and behavior of polymeric materials for themselves.

A very large number of science and engineering courses taught in colleges and universities today do not involve laboratories. Although good instructors incorporate class demonstrations, hands on homework, and various teaching aids, including computer simulations, the fact is that students in such courses often accept key concepts and experimental results without discovering them for themselves. The only partial solution to this problem has been increasing use of class demonstrations and computer simulations.

We propose to develop a set of hands on discovery based experiments which students can perform for themselves.

The experiments for this proposal are based on two themes:
1) where possible, actual materials commonly utilized in common consumer products will be employed, and
2) a set of special materials will be developed which the students can utilize to directly <u>see</u> complex concepts.

In both cases, the experiments and observations will utilize only the students' senses for transduction and detection.

We are ~~proposing the~~ develop~~ment of~~ ing a completely self contained polymer lab which, although packaged like a textbook, will contain within it <u>all</u> of the materials,

G

deduced. For example, we now routinely prepare surfaces with a continuous spatial gradient in wetting, as indicated in Figure 1. Two such surfaces placed together with a small separation, allow the phenomenon of capillarity as a function of wetting or contact angle to be dramatically demonstrated. Such basic concepts of surface energy, hydrophobicity, and capillarity are directly observed and make a lasting and permanent impression. One does not need to graph or correlate the results of the experiment. One simply sees the correlations vividly.

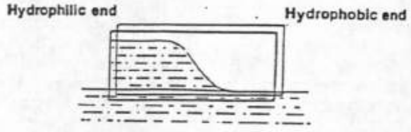

Fig. 1. Capillary rise method for investigation of wettability gradients. Two transparent plates with wettability gradients are put together with a support that separates the plates. The lower edges of the parallel plates are then brought into contact with a trough filled with water. Water moves upward between the plates and the height of the liquid meniscus is determined by the wettability of the surface of the plates (from Ref. 11).

H

We propose to utilize the concept of gradients to permit students to directly observe complex polymer phenomena, utilizing temperature gradients, composition gradients, surface energy gradients, and electric fields. We are unaware of any other groups attempting to develop and apply gradient surfaces for science and polymer education.

The approach is innovative and original. Gradients are used in particular areas of research. For example, biochemists commonly use gels with a gradient in cross link density, thereby developing a gradient in porosity. This is widely used in electro phoresis for protein analysis and separation (19). Polyelectrolyte gradient gels are used in electric fields to produce a gradient in pH, which allows the separation of macromolecules on the basis of net charge (19). Gradients in surface to volume ratio have been used to study concentration and mass transport dependent effects (12, 13).

I

3. Expected Results:

We expect to develop, produce, and characterize four different gradient materials in thin sheet forms suitable for the direct observation of a range of basic physical/chemical phenomena related to macromolecules.

Since so many of the properties of polymer materials are time and temperature dependent, it is almost mandatory to be able to produce different temperatures to permit such observations. A simple temperature gradient device used with gradient materials allows a wide range of relationships to be directly observed.

J

We ~~expect to successfully~~ are develop ing a simple thermal gradient device powered by a flat battery similar to those used in Polaroid film packs (18) or by an AC adaptor/battery replacement power source.

equipment, and information needed to directly discover and experience key concepts related to polymer materials. We expect that such a Labless Lab Book will be widely adopted as a supplement to the more conventional polymer science and engineering textbooks, particularly in those courses which do not have a laboratory section or component.

⑥

We expect to eventually expand this approach to a wide variety of science and engineering courses. It is appropriate to begin with polymer materials, however, because polymeric materials are so readily available for a wide variety of applications and because they exhibit a range of phenomena which are very easy to observe, experience, and discover.

There is considerable interest in effective polymer education (3). The American Chemical Society Division of Chemical Education often includes polymer related articles in its Journal of Chemical Education (4, 5) and in its sessions at the American Chemical Society annual meetings. The ACS also has a Polymer Education Committee, as does the Society of Plastic Engineers (SPE). Polymer education is also of interest to the American Institute of Chemical Engineers (AICHE) and the Materials Research Society (MRS). There is a Polymer Education Center at the University of Wisconsin, Steven's Point and a Polymer Education Newsletter (3). The Institute for Chemical Education at the Department of Chemistry at the University of Wisconsin, Madison, is also active in providing a variety of educational materials for discovery based chemistry and polymer education (6).

These activities are all helpful and indeed have greatly stimulated our efforts ~~this proposal~~. However, the typical instructor, particularly in relatively large enrollment classes, often does not have the time or the inclination to assemble the materials, components, and equipment necessary to put together an effective discovery laboratory, particularly if the class is a lecture only course, which is typical for many introductory material science and polymer science courses.

2. Innovativeness and Originality:

Materials, polymers included, are developed for commercial application and for meeting some particular consumer or industrial need. We are ~~proposing the development~~ of materials specifically for science education, and then utilizing these materials, together with others, in an inexpensive, completely self-contained polymer materials science kit. ~~We call it *The Labless Lab.*~~ m 9

Ⓗ

With these special materials the student can directly observe physical and chemical parameters and materials behavior. This is possible by utilizing what we call gradient materials and, in some cases by what is now being called "intelligent materials"(20). We have been utilizing gradient surfaces for many years in our study of the surface properties and biocompatability of medical polymers (7-9). We are now using these surfaces in biomaterials courses (10), because integration of materials and devices with surrounding tissues and the biocompatability of materials and devices tends to be a strong function of the surface properties of the materials (surface free energy, polarity, hydrophobicity, charge density, roughness, and surface dynamics), which play important roles in various biocompatibility situations (27,28).

The gradient surface is one in which a distinct surface property is varied continuously from one end of the sample to the other (11). Exposure of a single surface to the appropriate biological environment permits a qualitative assessment of a wide range of functions and activities, thereby allowing general concepts to be discovered and

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We also expect to incorporate various means for the optical observation of polymer behavior, including the use of polarized light. A device for producing a simple electric field source and electric field gradient will also be produced.

We expect that at the conclusion of Phase I we will have established the feasibility of a Labless Lab for polymeric materials. Concurrently with these studies, we will be assembling and developing appropriate nongradient samples for more traditional experimentation and observation (14-16).

The materials and methods developed during the earlier part of this Phase I will be tested in the Spring of 1994 in an introductory polymer materials course at the University of Utah offered and taught by J. Andrade (16). Thus we will have the benefit of rigorous field testing of the concepts and prototype of this Phase I project, prior to the completion of the project report and the submission of the Phase II application.

Phase II will expand these efforts to incorporate the full range of polymer science concepts and topics (4, 5, 14-16). During Phase II and on into Phase III we will then scale up the production of the materials in a cost effective manner and provide the further materials and information needed for a comprehensive labless lab for polymer materials. The Labless Lab will then be published, assembled, and given wide commercial distribution during Phase III.

4. Commercial Potential and Follow-On Funding:

Of the some 3,000 higher education institutions in the United States, it is expected that at least 500 offer introductory material science/materials engineering courses, all of which contain a polymer materials component. In addition it is estimated that there are some 200 schools which offer special courses in polymer materials (1). Roughly 50,000 introductory materials science textbooks are sold annually in the United States (2).

We do not know the specific numbers for introductory polymer materials texts (14-16) but an estimate in the range of about 10,000 is perhaps reasonable. In addition there are a wide variety of courses, workshops, and related educational activities in private industry and by commercial education services. In fact, this number is probably much greater than the number of individuals taking polymer materials related courses in colleges and universities.

Thus, we think that a Labless Lab: Polymer Materials could have a market as great as 100,000 units per year, particularly if one includes the fact that it would be of interest to high school students and for science fair projects, as well as packaged and made available for the science kit and science gift market (17).

The Labless Lab: Polymer Materials would have to sell in the range of $30-$50. A simple Explorabook, from the Exploratorium and Klutz Press, which we have alluded to earlier, sells in the range of $17-$25, and is the largest selling children's science book in the United States today.

Given that materials science and polymer materials textbooks tend to sell in the range of $40-$50 (2, 14, 15) and that lab fees in many universities are in the range of $50-$100 per course, a retail selling price in the range of $50 appears reasonable. Given typical distributor mark ups of 50-100%, it appears that the total sales from such a product could be in the range of $1-$2 million per year.

Various components of the kit may be marketable separately as scientific and technical novelties and curiosities. We call these "Technurios". The novelty and gift market is truly very large (17). This is very important for science education, however, because these technurios could be packaged in such a way that they educate the buyer or recipient and thereby contribute to the general science literacy and science education of the population (29).

We will work with the authors of popular polymer materials science textbooks and with their publishers during Phase II to ensure that the Labless Lab works well as an adjunct and supplement to existing textbooks. We have made some preliminary inquiries with one of the publishers and there is considerable interest. We expect that the major funding for the Phase III component would come from equity investors in the Salt Lake City area. Preliminary discussions with several investors who are friends of the company and are genuinely interested in the enhancement of science education suggest that they will indeed come forward with the appropriate financial resources, particularly if the Phase II grant is awarded. These details would of course be submitted with the Phase II application.

PSI now has two products in the science education market; Night Life: Science in the Dark, a bioluminescent science kit for upper elementary and junior high students. Teachers' versions of Night Life are also available. This kit is now being distributed by Science and Nature Distributors, a major U.S. distributor of science educational products. GALAXSEA: Bioluminescent Plankton is an adult science educational product only now beginning to be marketed. Although these products are designed for a different market segment than the Labless Lab: Polymer Materials, they do demonstrate PSI's commitment to taking concepts and ideas to the commercial sector. We are very confident of being able to successfully market the Labless Lab in the future.

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F. PHASE I RESEARCH OBJECTIVES:

1. Develop a simple battery powered device for producing thermal gradients in the range from room temperature to 50-60° C. Polymers can be selected with glass transition temperatures and melting points well within this range. This is a safe, easily accessible temperature range with which to observe many of the temperature dependent phenomena appropriate to polymer materials.

2. Select several homopolymers with glass transition temperatures (Tg) below room temperature, above 60° C, and in the mid range of the temperature gradient device (about 35° C). These will likely be poly alkyl methacrylates of the appropriate chain length (28).

3. Prepare a homopolymer with a plasticizer gradient to show the effect of low molecular weight additives on the Tg and mechanical properties of commercial polymers. This will likely be common polyvinyl chloride (PVC) with the conventional dioctyl phthalate plasticizer.

4. Select and produce a homopolymer with a gradient in cross link density from one end of the sample to another, so that it behaves as a very weak elastomer at one end, as a very rigid material at the other, and as a typical high strength elastomer in the middle. This dramatically demonstrates the effect of cross link density and molecular weight between cross links on the mechanical and physical properties.

5. Prepare 2 copolymer gradients:

One is based on differences in side chain volume and flexibility, such as methyl methacrylate and octyl methacrylate. The 100% PMMA end will be rigid. The 100% POMA end would of course be soft and flexible, with a continuous gradient in composition and properties in between, demonstrating the effect of excluded volume, packing, and internal plasticization.

The second is based on differences in monomer polarity. The preliminary choice here is methyl methacrylate/hydroxyethyl methacrylate. The PMMA end is rigid, hydrophobic, and non swelling or non absorbing in aqueous solution, whereas the PHEMA end, although rigid when dry, readily absorbs and takes up water, thereby becoming highly plasticized and behaving as a soft hydrogel. A continuous variation in properties in the middle of the sample demonstrates the effects of comonomer polarity and composition on a wide range of properties and behavior.

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6. A special gradient polymer to demonstrate the effects of charge, pH, and electric field. This one requires more thought, but initially possibly a HEMA/methacrylic acid gradient copolymer (28). Such a sample would have dramatic swelling in water as a function of pH and will respond to a uniform electric field as a function of composition and pH (21-25).

7. A temperature responsive homopolymer designed to have a lower critical solution temperature around 35-40° C, in the middle of our thermal gradient, thus demonstrating solubility and phase behavior of macromolecules (20, 26).

8. Polymer surfaces with a continuous wettability gradient. This would likely be polyethylene treated with a corona discharge designed to produce a gradient in surface modification and therefore in wetting (10) (Figure).

G. PHASE I RESEARCH PLAN:

Objective 1: Simple thermal gradient device.

The initial design for this device is based on a commercial thermoelectric element manufactured by Melcor Thermoelectrics, Inc. One of these elements is used in the Coleman cooler/heater designed for automobile use. Although this type of thermoelectric element is relatively expensive for our labless lab purposes at this time, of the order of $10, we expect that that price will drop substantially, and that we will be successful in developing negotiations with the vendor or with competitive vendors for an appropriate cost-effective device. We also plan to experiment with a battery/AC adapter based device. Preliminary experiments by Mr. Mike Goodwin at the University of Utah suggest that both approaches will prove feasible (30).

We will experiment with the geometry of the device including special designs to radiate heat to the surrounding ambient environment. The metal surface of the device would be encapsulated in a fluoro-polymer to minimize its adhesion with the polymer gradient samples. The device will also include a liquid crystal thermometer to read out temperature as a function of position.

Objective 2: Selected Tg homopolymers.

J. Andrade's group at the University of Utah has had considerable experience with methacrylate polymers and copolymers for biomedical applications (27, 28). Polymethyl methacrylate will be used as the high Tg polymer (about 130° C). Polyoctyl methacrylate is the low Tg polymer (about -60° C). Polyethyl or polypropyl methacrylate is the midrange Tg polymer.

Mr. Robert Larsen has been working with Polymethyl-methacrylate/Polyalkyl methacrylate homopolymers in his undergraduate Bachelors of Science thesis in the Department of Materials Science at the University of Utah. Mr. Larsen has developed prototype samples useful for the labless lab project. He would likely be employed on this project as one of the undergraduate assistants to make the gradient polymers which are proposed later (31).

We may have to experiment with some divinyl cross linker component during polymerization to achieve the physical and mechanical properties suitable for the Labless Lab sample. Putting such a nongradient sample perpendicular to the thermal gradient will provide uniform heating of the sample and will permit its behavior at that temperature to be observed. Orienting the same sample along the gradient and then pulling or tugging on the sample as a function of position, i.e. temperature, will clearly demonstrate the effect of temperature on the mechanical behavior at that particular composition.

Objective 3: Gradient and plasticizer properties.

Polyvinyl chloride is a rigid, relatively hard polymer whose Tg is considerably above room temperature. Polyvinyl chloride is made into a flexible readily formable and relatively soft polymer by the addition of low molecular weight plasticizer, generally di-octylphthalate (30). We will provide samples of unplasticized PVC and PVC plasticized at different levels as pure individual samples.

We also wish to develop a plasticizer gradient in PVC. Probably the simplest way is to take a fully plasticized PVC and to extract plasticizer by immersing the PVC film in a solvent (a good solvent for the plasticizer, a poor solvent for PVC) and then removing the film at a controlled rate from the solvent container. Different parts of the PVC polymer film will have been exposed to solvent for different lengths of time, thereby extracting different amounts of plasticizer. By programming the withdrawal rate carefully and exposing the thin film sample to a slightly elevated temperature to facilitate diffusion, a plasticizer gradient can be readily produced.

Objective 4: Cross linker concentration.

We will attempt to produce 2 different polymer cross link gradients. One will be a conventional hydrocarbon rubber with different degrees of cross linking, possibly by using a photo activable cross linker. This would also have the benefit of including photochemical processes in the Labless Lab Book.

A photochemical approach using a thin, transparent rubber film has some distinct advantages, because virtually any gradient in cross linker concentration can be established, simply by masking or filtering the light source used for photo activation. J. Andrade's group at the University of Utah has been using photo activable reactions for surface modification and for the preparation of gradient surfaces.

Another approach to a cross link gradient is to use the standard gradient electrophoresis gel for protein sieving and molecular size separation. This is essentially a polyacrylamide polymer with a bisacrylamide cross linker gradient. Again the University of Utah lab has considerable experience in gradient electrophoresis using polyacrylamide gel systems (19). This also has the advantage that it may serve as the basis of future developments during Phase II for pH gradients and even 2D gradients such as is commonly used now in 2 dimensional gel electrophoresis (18).

Imagine a conventional elastomer containing a cross link gradient and suspended from a large clip or holder. The large clip will encompass the whole width of the sample, holding it in mid air; small localized clips on the bottom, each containing a constant identical weight, cause the sample to deform to different lengths as a function of distance, dramatically demonstrating the extensibility of the polymer as a function of its cross link density. Such an experiment will dramatically demonstrate the effect of cross link density on modulus and mechanical behavior.

the students to come up with their own observations and even hypothesis as to what is going on - that is the very essence of science. We feel it should be practiced in every single course.

This particular sample and observation may well be a capstone project or experiment at the conclusion at the polymer materials course, enabling the students to attempt to apply the various concepts they have learned and understood to a more complex and less well known problem.

Most of the work on electrically responsive polymers deals with aqueous systems using various derivatized acrylamides and methacrylates. The trick is to get an appropriate hydrophilic/hydrophobic balance and a balance of charged groups which will respond to the electric field (20-26).

Gradients are very useful here because the effects generally occur only in a very narrow range of conditions. Although at this point our goal is simply to produce a polymer of fixed composition with which to demonstrate electrical effects, in the future we may want to produce a gradient polymer which is electrically responsive only in some particular composition range, thereby directly demonstrating the critical conditions required for such dramatic effects (23).

We will probably begin with the relatively simple systems as described by Tanaka (23, 24) and move on to the more complex systems as recently described by Osada (21, 22) and Kim .

Objective 7: Temperature responsive polymers.

These systems are also based on water soluble polymer networks in which there is a critical balance of hydrophilic and hydrophobic characteristics, thus providing a critical balance between solubility and insolubility in aqueous solution (20, 26). The relative ratio of the hydrophobic character is a function of temperature. Thus over a critical temperature range the solubility characteristics change dramatically. These systems are often based on cross linked polyalkyl substituted acrylamides and their behavior interpreted in terms of swelling and rubber elasticity concepts.

In such systems, swelling or solubility decreases as temperature increases, just the opposite of what is taught in basic chemistry. This is of course due to the hydrophilic/hydrophobic balance and the major effect which entropy has on the behavior of polymers.

Polyisopropyl acrylamide for example, exhibits a very sharp change in equilibrium swelling around 33° C, the middle range of our temperature gradient device. A gradient sample, observed on the thermal gradient device, would be extremely interesting. The collapsed or insoluble polymer compositions are turbid, whereas the swollen or soluble polymer compositions tend to be clear, producing a simple visual observation of the lower critical solution temperature as a function of composition.

Objective 8: Surface gradients.

Although most of our experience in making surface chemical gradients involves chemical derivatization of the surfaces of appropriately modified glass and quartz materials (7,8), we have also had some experiment with radio frequency plasma discharge surface modification, including the preparation of gradient surfaces in

Objective 5: Comonomer gradients.

This relates closely to that in Objective 2 above. In this case, we will use 2 monomers to prepare a compositional gradient. We think the best way to do this is to use a technique which we have used widely for gradient surfaces, that is to have 2 solvents, one containing monomer A, the other containing monomer B, which are partially miscible and in which the 2 monomers are mutually soluble, but with different solubility limits. A concentration gradient develops due to diffusion. At time zero when the 2 solutions are layered, the upper half is pure monomer A and the lower half is pure monomer B. As time proceeds, the two solvents inter diffuse, thereby drawing the 2 monomers into each of the two compartments. With time, this sets up a diffusion gradient. When the desired gradient in composition is achieved, which needs to be determined by experiment, we will initiate a free radical polymerization reaction, via a photoinitiator contained in both solutions. There are some complexities in the approach which involve the relative solubilities of the photo initiator and of the monomers in the two solvents, but these can be addressed.

Another way to accomplish such a gradient is to use the same solvent for each monomer solution; this is possible in the case of many of the methacrylate monomers. The 2 solutions are delivered into the reaction chamber in such a way that the mixing leads to a gradient which can then be instantaneously polymerized. This approach is certainly desirable for scaleup, and would probably be required for inexpensive sample preparation. This is a continuous polyimerization process which can be highly efficient and cost effective. This also has the advantage that different kinds of A + B composition gradients can be produced, simply by controlling the flow rate and the mixing parameters.

Mr. Robert Larsen is doing some preliminary co-monomer gradient work in his current studies for his Bachelors thesis at the University (31).

Objective 6: Polymers responsive to electric fields.

There is a great deal of interest in so-called "intelligent" or stimuli - responsive polymer systems (20). There has been much discussion in the popular scientific press about polymers which are responsive to temperatures, electric field, pH, optical radiation, particular ions, and chemical solvents (20). Students are very interested in this area, in large part, because it is popular and current.

This particular objective is a bit speculative, particularly in terms of its feasibility for an inexpensive Labless Lab Book. Nevertheless, it is so intrinsically interesting that we want to begin to probe in this area in the hopes of coming up with a practical sample which can indeed be incorporated in the Labless Lab.

S.W. Kim has considerable experience with the development of electrically responsive polymer networks for drug delivery applications. The group of Osada in Japan recently demonstrated a polymer gel which can be made to move by electrical stimulation (20-22). Tanaka and others have demonstrated other significant changes of gels in electric fields (21-25).

Many of the DC electric field effects on gels and polymers are due to changes in ionization due to changes in local pH. Other effects are more subtle and may involve competitive binding of various electrically sensitive species. Nevertheless, the results are of sufficient intrinsic interest that they merit some attention and consideration for education purposes. It is also wise to include in each course and text examples of the state of the art of the field, showing that everything is not cut and dried, and encouraging

wettability by this method. We have had a close collaboration with a group in Korea which has worked extensively with corona discharge and the preparation of wetting gradients by using a gradient in the corona treatment (9).

Given that corona discharge is widely used for surface modification of polyethylene and is a reliable, inexpensive treatment process, we propose to use corona treatments to develop the surface wetting gradient.

In summary, objectives 1, 2, 7, and 8 are very straight forward and we anticipate completing those early in the project. Objectives 3, 4, 5, and 6 are a little more sophisticated, although we anticipate no major problem in the production of these surfaces and materials.

K

The question now is what does one do with these novel and unique polymer samples for science education? Table 1 presents a typical topic outline for a typical Introduction to Polymer Materials course. This represents Materials Science and Engineering 519, the required polymer course for Materials Science majors at the University of Utah (16). This is the terminal polymer materials course for those majors who do not go on into the polymer science track.

The Table presents the general topic, followed by a column of commercial or conventional polymer examples, followed by a column of the special materials we propose to develop in this project. The table indicates how the new materials and existing materials are used by students to discover and observe the various concepts, properties, and behavior.

We certainly do not expect to cover all concepts and topics in polymer science with the 8 objectives of this Phase I SBIR. However, many of the other materials and experiments which are required to provide a fully balanced and reasonably complete laboratory/discovery experience in polymer materials are already available and have been reasonably well described in the polymer education literature(3-5).

A major task of Phase II will be to refine and scale up the materials developed and produced during Phase I, and to assemble all of the other components and materials required for a complete and comprehensive laboratory experience.

H. COMMERCIAL POTENTIAL AND FOLLOW-ON FUNDING:

This was discussed in Section E.4.

I. RELATED RESEARCH

This was discussed briefly in Section G, Objective 2 and Objective 8 (above) and in Section E.2. and E.3.

J. SENIOR PERSONNEL/VITA:

Dr. Li Feng is a research engineer with Protein Solutions, Inc. Dr. Feng recently completed his Ph.D. in Materials Science and Engineering at the University of Utah, working on protein interactions with pyrolytic carbon surfaces. He has extensive experience in polymer materials and polymer processing and has a strong interest in science and engineering education. He has taken the full complement of polymer materials science and engineering courses during his graduate studies and has had extensive experience with polymer sample preparation, surface modification, and

Table 1 Major Topics in a One Quarter (10 weeks) Undergraduate Course, Introduction to Polymer Science and Polymeric Materials (MSE 519, University of Utah) (16)

Topic	Key Concepts	Conventional Materials/Methods	COMMUNICATIVE ~~Gradient~~ Materials (~~Phase I~~)
Polymer Applications	Wide range of Properties and compositions	Examples from consumer products and engineering devices & machines	None
Macro molecules	High molecular weights. packing, entanglement	Individual examples	MW gradients* comonomer gradients
Polymerization and copolymerization	Properties = f (composition, molecular weight)	Individual examples	MW gradients* comonomer gradients
Morphology and Structure	Packing, Ordering, Melting	Individual examples, molecular simulation	Crystallization, annealing, ordering as f (T, t), comp. gradients
Block copolymers	Phase separation, incompatibility	Blends, diblock - triblock - copolymers	Blend gradient*
Solubility and solutions	Solution Interactions and thermodynamics	Individual examples - MW, polarity, Temp.	Temp. gradient - LCST composition gradient
T - t Effects	T - t superposition; effect of properties on T and t	Specific examples	T gradient/comp. gradient
Cross-linking	Networks, elasticity, viscoelasticity	Individual examples	Cross link gradient; mechanical response
Additives	Plasticization	PVC - Plasticizer - individual samples	Plasticizer gradient, T gradient
Surface Properties	Wetting/surface modific.	Individual Examples	Wetting gradients, capillarity
Processing	Fiber formation, film molding	Thermoplastic, thermoset, T and processing	T gradient, cross link gradient composition gradient
Adhesives	Adhesion/surface properties	Hi and low energy polymers, contact angle, peel tests	Surface property gradient
Electrical fields	Conductivity, ionization, solubility	Mainly conductive polymers	Ionogenic polymers & biopolymers; electrically responsive polymers; T gradient; LCST; Elect. responsive
Biopolymers	structural proteins	Silk, collagen	Polypeptide gradients*
Environmental issues	Cost, energy, solid waste, biodegradation	Specific examples, classes, stability	Composition/morphology gradients; stability

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~~* Phase II activities.~~

Vita

Li FENG, Ph.D.

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EDUCATION

PhD. Materials Science, University of Utah, Salt Lake City, Utah, March, 1993.
ME. Materials Science, University of Utah, 1990.
+Course GPA 3.8/4.0, emphasis in surface science, polymer materials, biomaterials, protein biochemistry, and protein adsorption. Additional courses in metallurgy, solid state physics, electronics, numerical analysis, statistics, and computer science.
+Dissertation: Biomedical carbon surfaces and their interactions with plasma proteins.

MS. Polymer Physics, Zhongshan University, Canton, China, December, 1981.
+Course emphasis in polymer science, quantum chemistry, structure of solids, and composites.
+Thesis: Solid-state polycondensation of nylon 66 salt and carbon fiber-nylon composites.

BS. Chemistry, Zhongshan University, Canton, China, July 1978.

EXPERIENCE

Research Engineer (6/1993-present) Protein Solutions, Inc., Salt Lake City, Utah.
+Educational materials and products for polymer science and surface chemistry.

Postdoctoral Fellow (Part-time, 2/1993-11/1993) Center for Biopolymers at Interfaces, University of Utah.
+Protein structure analysis and computer simulation-studying relationship between protein structure and adsorptivity.

Research Assistant (1987-2/1993) Department of Materials Science and Engineering, and Center for Biopolymers at Interfaces, University of Utah.
+Plasma protein interactions with biomedical carbons, silica, and gold-exploring factors that determine a material's blood compatibility through protein adsorption studies.
+Surface analysis by Scanning Tunneling Microscopy-observing surface structures of biomedical carbons, and adsorbed proteins on graphite.
+Surface structures and properties of biomedical carbons-correlating surface nature to protein adsorption behavior.
+Electrochemical properties of carbon and gold.

Teaching Assistant (1988-1989) Department of Materials Science and Engineering, University of Utah.
+For classes of applied polymer science, physical nature of surfaces, and polymer surface characterization.

Faculty Member (1981-1986) Department of Polymer Materials, Chengdu University of Science and Technology, Chengdu, China.
+Teaching polymer synthesis technology on industrial scales.
+Research on emulsion polymerization, surfactant synthesis, and latex applications.

Research Assistant (1978-1981) Zhongshan University, Canton, China.
+making fiber-polymer composites and studying interactions between reinforcements and matrixes.

characterization. This experience, coupled with his unique presentation and teaching skills, provide him with the background necessary for the successful conduct of this project. He joined Protein Solutions in June, 1993 at the conclusion of his Ph.D. studies. He is currently 60% time with Protein Solutions and 40% time with the University of Utah on a project with the Center for Biopolymers at Interfaces. This latter project is a temporary assignment and is expected to conclude at the end of 1993 at which time he will be full-time with Protein Solutions.

J.D. Andrade is President of Protein Solutions, Inc., and also serves as Professor of Materials Science and Engineering and of Bioengineering at the University of Utah. Joe has taught the undergraduate basic Materials Science course many times, and has a strong personal research program dealing with gradient surfaces for biomaterials research and development. He founded Protein Solutions, Inc. specifically to develop materials and methods by which to teach science and engineering concepts in a highly effective, discovery-based manner. The company prefers to use phenomena which are the subject of current research and which are intrinsically interesting and motivating. One example is their development of bioluminescence, light generated by living systems, as a motivational vehicle and tool for the discovery and study of integrated science concepts at the elementary and Jr. High level. Joe's strong materials science and polymer materials background, and his strong interest and background in science and engineering education, are ideally suited to this project (see vita, following pages). Although Joe is not budgeted on this grant, he has been involved with the labless lab concept in its formative stages and has supervised two undergraduate Materials Science and Engineering students at the University of Utah who have done their Bachelor's thesis on this concept (30, 31). Drs. Andrade and Feng have worked closely together for the past 5 years. As President and Chief Scientific Officer of PSI, Andrade will serve as the key technical advisor to the project.

Mr. Andras Pungor is a Research Associate in the Department of Bioengineering. Mr. Pungor has a Master's Degree in Electrical Physics from Hungary, and has had considerable experience as a Physics instructor in his home country. He is a member of the technical staff of the Department of Bioengineering and the Surface Analysis Laboratory at the University of Utah. The laboratory does a variety of contract analytical and development work for industry. He has unique and special skills in the development of devices and apparatus involving electronics, optics, and mechanical components. He will advise and aid in the development of the simple power source and circuit for the electrically responsive polymers and the simple device for producing a thermal gradient. His time and supplies will be handled on a fee for service basis and billed via the Surface Analysis Laboratory at the University of Utah.

Undergraduate student(s): The University of Utah's Materials Science and Engineering Department has an undergraduate research thesis requirement. The students in this department are always looking for suitable projects, preferably projects which provide some financial renumeration. One or two such students with a strong polymer science background will be selected to work on this project. The timing is almost ideal as the students generally do most of their project work in the January to June time frame of their senior year. Therefore the January to June 1994 duration of this project matches that level of effort. The students will work under Dr. Feng's supervision at the Protein Solutions, Inc. laboratories in the University of Utah's Research Park.

Mechanic (1971-1975) Xingan Electronics Corp., Xingan, Guangxi, China.
+Operating on machine tools.

Special Expertise: carbon & polymer materials, electrochemistry, colloid chemistry, scanning tunneling microscopy, x-ray photoelectron spectroscopy, calorimetry, two-dimensional electrophoresis, radioisotope-labeling, and protein structure.

Other Experience: computer literacy (PC, MAC and UNIX), computer programming, ellipsometry, contact angle, SEM, TEM, NMR, IR, UV, x-ray diffraction, polymer processing, mechanical property measurements, polymer & organic syntheses, analytical chemistry and metallurgy.

MAJOR PUBLICATIONS

L. Feng and J. D. Andrade, "Protein adsorption on low temperature isotropic carbon: V. What makes it blood compatible via protein adsorption?" Submitted to *J. Biomed. Mater. Res.*

L. Feng and J. D. Andrade, "Protein adsorption on low temperature isotropic carbon: IV. Competitive adsorption studied by two-dimensional electrophoresis," Submitted to *Colloids and Surfaces.*

L. Feng and J. D. Andrade, "Protein adsorption on low temperature isotropic carbon: III. Isotherms, competitivity, desorption, and exchange of adsorption of human albumin and fibrinogen, " Submitted to *Biomaterials.*

L. Feng and J. D. Andrade, "Protein adsorption on low temperature isotropic carbon: II. Effects of surface charge of solids, " Submitted to *J. Colloid Interface Sci.*

L. Feng and J. D. Andrade, "Protein adsorption on low temperature isotropic carbon: I. Protein conformational change probed by differential scanning calorimetry," Submitted to *J. Biomed. Mater. Res.*

L. Feng and J. D. Andrade, "Double layer capacitance and charge transfer reactions on various carbon electrodes," in preparation.

L. Feng and J. D. Andrade, "Surface Atomic and Domain Structures of Biomedical Carbons Observed by Scanning Tunneling Microscopy (STM)," *J. Biomed. Mater. Res.*, **27**, 177-182 (1993).

V. Hlady, J. D. Andrade, C. H. Ho, L. Feng and K. Tingey, "Plasma protein adsorption on model biomaterial surfaces," *J. Clin. Materials* (1993), in press.

L. Feng, J. D. Andrade, and C. Z. Hu, "Scanning tunneling microscopy of proteins on graphite surfaces," *Scanning Microscopy*, **3** (2), 399-410 (1989).

L. Feng, C. Z. Hu, and J. D. Andrade, "Scanning tunneling microscopic images of adsorbed serum albumin on highly oriented pyrolytic graphite," *J. Colloid Interface Sci.*, **126** (2) 650-653 (1988).

L. Feng, C. Z. Hu, and J. D. Andrade, "Scanning tunneling microscopic images of amino acids," *J. Microscopy*, **152**(Pt 3) 811-816 (1988).

C. Z. Hu, L. Feng, and J. D. Andrade, "Surface structure of pyrolyzed polyimide," *Carbon*, **26**, 543 (1988).

K. Li, L. Feng, and W. Lu, "Latex pressure sensitive adhesives of polyacrylates," *Special Rubbers*, No. 2, 5 (1984), in Chinese.

H. Zeng and L. Feng, "Investigations of solid state polycondensation of nylon 66 salt," *Polymer communications*, No. 5, 332 (1983), in Chinese.

H. Zeng and L. Feng, "Studies of solid-state polycondensation of nylon 66 salt with carbon fiber composites," *Chem. J. Chinese Universities*, **4**, 610 (1983), in Chinese.

H. Zeng and L. Feng, "Interfacial effects and failure mechanisms of carbon fiber composites with nylon 66 prepared by in situ solid-state polycondensation," *Applications of Engineering plastics*, No. 8, 8 (1983), in Chinese.

K. CONSULTANTS AND SUB CONTRACTS:

None, although several members of PSI's Scientific Advisory Board will provide gratis advice and input.

Dr. Jindrich Kopecek is Professor of Bioengineering and Pharmaceutics at the University of Utah. Dr. Kopecek is an expert on polymerization, particularly methacrylate and acrylamide-based systems. His pioneering work on hydrophilic methacrylates served as the scientific basis for the development of the soft contact lens industry. This work was done as a graduate student and later as a staff scientist at the Institute for Macromolecular Chemistry in Prague, Czechoslavakia. Dr. Kopecek joined the University of Utah 4 years ago as full professor and has a large and active research program dealing with the application of polymers as drug delivery devices. His synthesis and chemistry expertise will be applied to the development of materials with gradients in cross link density and comonomer composition. He will also be involved in the part of the project dealing with gradients in plasticizer composition. Dr. Kopecek is a popular and highly rated instructor and has a strong interest in science and technical education.

Dr. Vladimir Hlady is Associate Research Professor of Bioengineering. He has a very strong Physical Chemistry background and teaches in the area of Biomaterials, Surface Chemistry, Surface Engineering, and Interfacial Biochemistry at the University of Utah. For the past several years he has been developing gradient surfaces for the study of biochemical interfacial processes and for the development of bioengineering devices (7,8). He and his students are expert in the preparation and characterization of surfaces with spatial gradients in surface properties.

Dr. Sung Wan Kim is Professor of Pharmaceutics and Research Professor of Bioengineering at the University of Utah. Dr. Kim has a very large internationally acclaimed program in the application of polymers as medical devices and as drug delivery materials. Several years ago he became involved in a project which is best called, "Stimuli Response Polymers for Bioengineering Applications". His group has worked on temperature and electric field responsive polymer systems as gates in controlled release devices for drug delivery applications. Dr. Kim will advise and assist in the selection of an optimum polymer composition for the electrically sensitive polymer part of this project.

L. FACILITIES AND EQUIPMENT

The work on this project will be carried out by PSI, Inc. in its laboratories located in the University Research Park, 390 Wakara Way, Salt Lake City, 84108. PSI is a member of the Center for Biopolymers at Interfaces at the University of Utah, one of the State's Centers of Excellence. PSI is a key corporate participant in the University's Center for Integrated Science Education (CISE). PSI has a Technology Transfer agreement with the University of Utah Research Foundation. PSI's laboratories are equipped to perform the necessary biological, chemical, engineering, and evaluation studies. The laboratory space (1500 ft^2) includes a general chemistry lab, and normal office and instrument room space. Sophisticated equipment which may be required may be used by our team on a time-sharing cooperative basis at the University of Utah.

M. CURRENT AND PENDING SUPPORT

PSI has invested $70,000 (provided by its founders and major stock holders) in initial studies and product development. PSI is now discussing equity investments by a number of local investors and investment groups.

N. EQUIVALENT PROPOSALS

No similar proposal has been funded, is pending, or is about to be submitted by Protein Solutions, Inc. to the National Science Foundation or any other agency.

THE UNIVERSITY OF UTAH

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10 June, 1993

Li Feng
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Dear Li,

I have completed the feasibility calculations related to the development of a flat, inexpensive thermal gradient device. I can build and characterize these units for evaluation in your SBIR project the Labless Lab: Polymer Materials.

The Surface Analysis Lab - Department of Bioengineering - will invoice you for my time and materials.

I am looking forward to working with you.

Sincerely,

Andras Pungor