How to write a successful NSF proposal

The best things you can do to prepare:

- Be a proposal reviewer/panelist yourself.
- Meet with the NSF program director in your area.
- Read successful (and unsuccessful) proposals and their reviews.
- Ask a knowledgeable colleague to critique your proposal before you submit it.

Who are the reviewers?

Reviewers are typically busy academics like you. They appreciate *good basic science.*

Some will have intimate knowledge of the problem you are researching, *most will not.*

A clear, well-written proposal helps the second group appreciate the value of your ideas.

You will need to convince them *early* that the problem is important and that your idea is great.

Outline of a 15-page NSF proposal

1-2 pp. of broad context and background

- Why is the problem important?
- What is already known about it? (it's important to do your homework thoroughly here!! – shoot for 100+ references)
- What are the major goals for 5-10 years?

2-3 pp. of prior work/your current research on the problem

- Be explicit about the key contributions you have made (high profile, published papers are very useful here)
- This is a good place for the required "results from prior NSF support," if applicable.

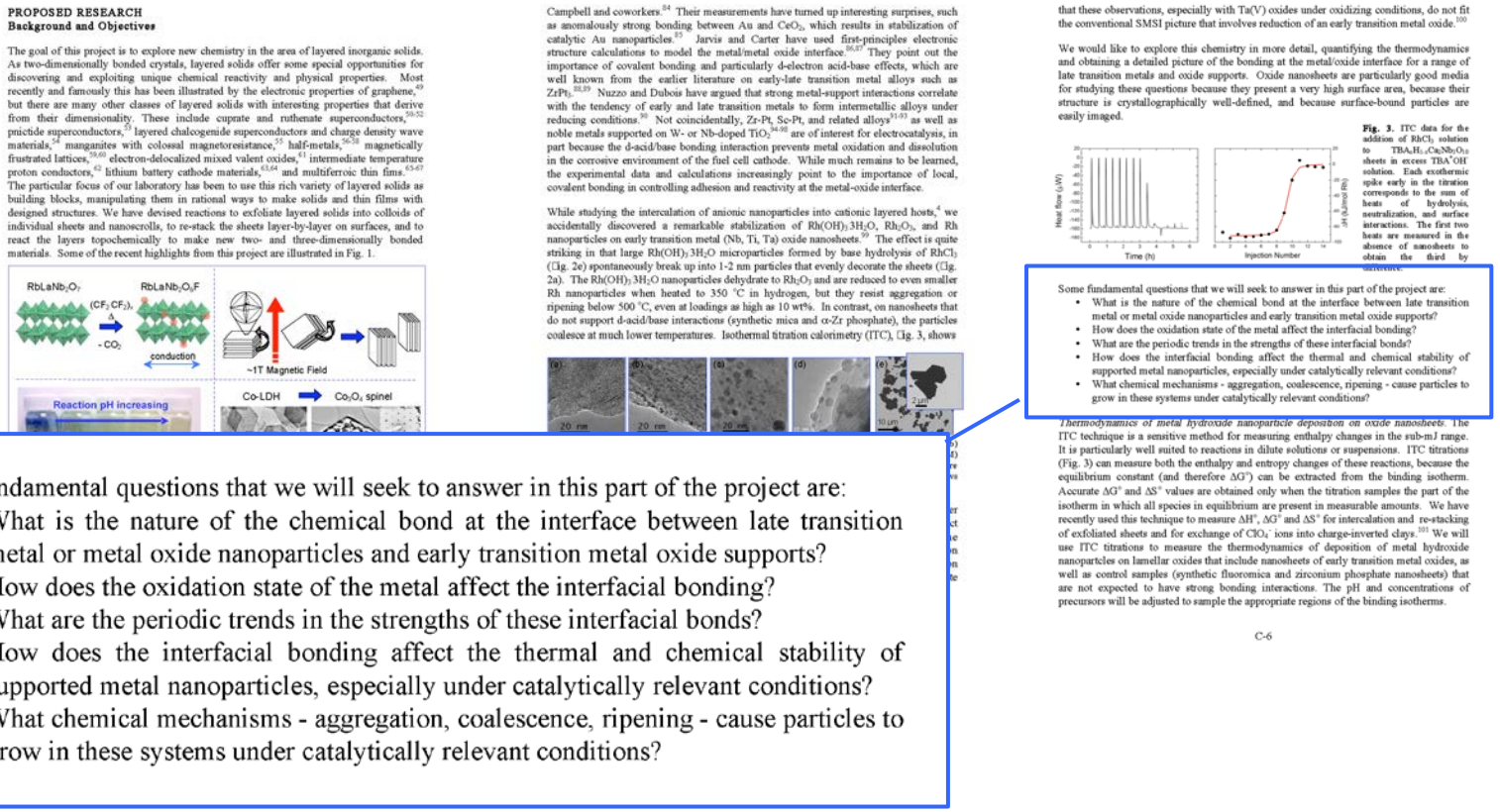
5-7 pp. of proposed work, well illustrated and focused on basic science questions. OK to intersperse some current work here.

Organization of the research section

Graphics are important: 1-2 per page

- Even small figures convey a lot of visual information, and help break up the text for the reviewer.

Bulleted questions are useful for the reviewer.



PROPOSED RESEARCH
Background and Objectives

The goal of this project is to explore new chemistry in the area of layered inorganic solids. As two-dimensionally bonded crystals, layered solids offer some special opportunities for discovering and exploiting unique chemical reactivity and physical properties. Most recently and famously this has been illustrated by the electronic properties of graphene,[49] but there are many other classes of layered solids with interesting properties that derive from their dimensionality. These include cuprate and ruthenate superconductors,[50-52] pnictide superconductors,[53] layered chalcogenide superconductors and charge density wave materials,[54] manganites with colossal magnetoresistance,[55] half-metals,[56-58] magnetically frustrated lattices,[59,60] electron-delocalized mixed valent oxides,[61] intermediate temperature proton conductors,[62] lithium battery cathode materials,[63,64] and multiferroic thin films.[65-67] The particular focus of our laboratory has been to use this rich variety of layered solids as building blocks, manipulating them in rational ways to make solids and thin films with designed structures. We have devised reactions to exfoliate layered solids into colloids of individual sheets and nanoscrolls, to re-stack the sheets layer-by-layer on surfaces, and to react the layers topochemically to make new two- and three-dimensionally bonded materials. Some of the recent highlights from this project are illustrated in Fig. 1.

RbLaNb$_2$O$_7$ → RbLaNb$_2$O$_7$F, $(CF_2CF_2)_n$, Δ, $-CO_2$, conduction

~1T Magnetic Field

Reaction pH increasing

Co-LDH → Co_3O_4 spinel

Campbell and coworkers.[84] Their measurements have turned up interesting surprises, such as anomalously strong bonding between Au and CeO_2, which results in stabilization of catalytic Au nanoparticles.[85] Jarvis and Carter have used first-principles electronic structure calculations to model the metal/metal oxide interface.[86,87] They point out the importance of covalent bonding and particularly d-electron acid-base effects, which are well known from the earlier literature on early-late transition metal alloys such as ZrPt.[88,89] Nuzzo and Dubois have argued that strong metal-support interactions correlate with the tendency of early and late transition metals to form intermetallic alloys under reducing conditions.[90] Not coincidentally, Zr-Pt, Sc-Pt, and related alloys[91-93] as well as noble metals supported on W- or Nb-doped TiO_2[94-98] are of interest for electrocatalysis, in part because the d-acid/base bonding interaction prevents metal oxidation and dissolution in the corrosive environment of the fuel cell cathode. While much remains to be learned, the experimental data and calculations increasingly point to the importance of local, covalent bonding in controlling adhesion and reactivity at the metal-oxide interface.

While studying the intercalation of anionic nanoparticles into cationic layered hosts,[4] we accidentally discovered a remarkable stabilization of $Rh(OH)_3·3H_2O$, Rh_2O_3, and Rh nanoparticles on early transition metal (Nb, Ti, Ta) oxide nanosheets.[99] The effect is quite striking in that large $Rh(OH)_3·3H_2O$ microparticles formed by base hydrolysis of $RhCl_3$ (Fig. 2e) spontaneously break up into 1-2 nm particles that evenly decorate the sheets (Fig. 2a). The $Rh(OH)_3·3H_2O$ nanoparticles dehydrate to Rh_2O_3 and are reduced to even smaller Rh nanoparticles when heated to 350 °C in hydrogen, but they resist aggregation or ripening below 500 °C, even at loadings as high as 10 wt%. In contrast, on nanosheets that do not support d-acid/base interactions (synthetic mica and α-Zr phosphate), the particles coalesce at much lower temperatures. Isothermal titration calorimetry (ITC), (Fig. 3, shows

that these observations, especially with Ta(V) oxides under oxidizing conditions, do not fit the conventional SMSI picture that involves reduction of an early transition metal oxide.[100]

We would like to explore this chemistry in more detail, quantifying the thermodynamics and obtaining a detailed picture of the bonding at the metal/oxide interface for a range of late transition metals and oxide supports. Oxide nanosheets are particularly good media for studying these questions because they present a very high surface area, because their structure is crystallographically well-defined, and because surface-bound particles are easily imaged.

Fig. 3. ITC data for the addition of $RhCl_3$ solution to $TBA_xH_{1-x}Ca_2Nb_3O_{10}$ sheets in excess TBA^+OH^- solution. Each exothermic spike early in the titration corresponds to the sum of heats of hydrolysis, neutralization, and surface interactions. The first two heats are measured in the absence of nanosheets to obtain the third by

Heat flow (μW) vs Time (h); ΔH (kJ/mol Rh) vs Injection Number

Some fundamental questions that we will seek to answer in this part of the project are:

- What is the nature of the chemical bond at the interface between late transition metal or metal oxide nanoparticles and early transition metal oxide supports?
- How does the oxidation state of the metal affect the interfacial bonding?
- What are the periodic trends in the strengths of these interfacial bonds?
- How does the interfacial bonding affect the thermal and chemical stability of supported metal nanoparticles, especially under catalytically relevant conditions?
- What chemical mechanisms - aggregation, coalescence, ripening - cause particles to grow in these systems under catalytically relevant conditions?

Thermodynamics of metal hydroxide nanoparticle deposition on oxide nanosheets. The ITC technique is a sensitive method for measuring enthalpy changes in the sub-mJ range. It is particularly well suited to reactions in dilute solutions or suspensions. ITC titrations (Fig. 3) can measure both the enthalpy and entropy changes of these reactions, because the equilibrium constant (and therefore ΔG°) can be extracted from the binding isotherm. Accurate ΔG° and ΔS° values are obtained only when the titration samples the part of the isotherm in which all species in equilibrium are present in measurable amounts. We have recently used this technique to measure ΔH°, ΔG° and ΔS° for intercalation and re-stacking of exfoliated sheets and for exchange of ClO_4^- ions into charge-inverted clays.[101] We will use ITC titrations to measure the thermodynamics of deposition of metal hydroxide nanoparticles on lamellar oxides that include nanosheets of early transition metal oxides, as well as control samples (synthetic fluoromica and zirconium phosphate nanosheets) that are not expected to have strong bonding interactions. The pH and concentrations of precursors will be adjusted to sample the appropriate regions of the binding isotherms.

C-6

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What to propose

NSF supports *transformative* research but reviewers are *very conservative.* One bad score can kill your proposal.

Use the Eklund 1/3 – 1/3 – 1/3 formula:

- 1/3 of the research plan is devoted to ideas that you are *90% sure will work.*
- 1/3 is more exploratory (with contingency plans). This is where you convince the reviewers you are doing something novel.
- Final 1/3 can be really creative, but must acknowledge the risk.

Peter Eklund

What to propose

NSF supports ***basic scientific research*** but is responding to pressure to be more relevant/applied.

- If you can articulate your ideas in the form of *questions*, you are proposing to do basic science.

- A good strategy is to use a list of *questions* as the outline in your proposed research section.

- Ask yourself (as the reviewer's will ask): Is what I am proposing at the intellectual forefront of the field?

Knowledge vs. widgets:

What will we learn that we don't know now?

Not: What will we have that we don't have now?

Selling a practical idea (if you must)

Not: We will develop a system that will diagnose cancer early, to the great benefit of humankind.

Instead:

It is important to diagnose cancer early because…

It can't be done now because...

We are going to make it possible by solving the following fundamental problems…

We will then demonstrate what we have learned in the following model system…

Outline of a 15-page NSF proposal (cont'd)

2 pp. of broader impact

- Integrating education and research
- Preparing students for careers in STEM
- Outreach beyond the university community

1 p. summary, timeline, human resources (optional)

- Briefly summarize key elements of the proposal
- Which students will perform which tasks (both research and education/outreach)

Final **1-2 paragraphs**, a conclusion about why this research is important, and what long-term benefit it will bring to the scientific community.

The most common reasons for negative reviews

- The proposed work is not novel (“it’s already been done”)
- The ideas are not exciting or significant
- No track record in the area, lack of preliminary data
- Not enough detail about what is being proposed
- Poor balance of proposed research/outreach
- The plan is too ambitious/not realistic
  - Avoid laundry lists of tasks and ideas!
- The proposal is poorly written
  - It should provide a concise review & road map for the work
  - Anticipate problems and their solutions
  - Spell check!
  - Print the proposal out and check it over carefully

Additional Resources

Cindy Grimm's website, How to Write an NSF Proposal (Washington U.)

http://www.cs.wustl.edu/~cmg/NSF/nsf.html

Susan Finger's website, Advice on Writing Proposals to the National Science Foundation (Carnegie Mellon)

http://www.cs.cmu.edu/~sfinger/advice/advice.html

Steven Driese's top 10 tips (from Gail Ashley/Rutgers)

http://sas.rutgers.edu/component/docman/doc_download/432-top-ten-tips-on-how-to-write-a-successful-nsf-proposal