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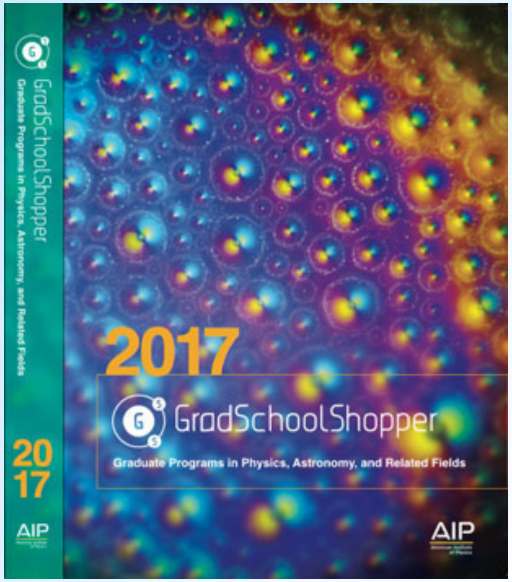

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11/04/17	09/29/17	10/06/17	09/15/17	12/04/17	12/15/17
02/03/18	12/29/17	01/05/18	12/15/17	03/05/18	03/16/18

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Overview

- The test consists of approximately 100 five-choice questions, some of which are grouped in sets and based on such materials as diagrams, graphs, experimental data and descriptions of physical situations.

- The aim of the test is to determine the extent of the examinees' grasp of fundamental principles and their ability to apply these principles in the solution of problems.

- Most test questions can be answered on the basis of a mastery of the first three years of undergraduate physics.

- The International System (SI) of units is used predominantly in the test. A table of information representing various physical constants and a few conversion factors among SI units is presented in the test book.

- The approximate percentages of the test on the major content topics have been set by the committee of examiners, with input from a nationwide survey of undergraduate physics curricula. The percentages reflect the committee's determination of the relative emphasis placed on each topic in a typical undergraduate program. These percentages are given below along with the major subtopics included in each content category. In each category, the subtopics are listed roughly in order of decreasing importance for inclusion in the test.

- Nearly all the questions in the test will relate to material in this listing; however, there may be occasional questions on other topics not explicitly listed here.

* Content Specifications

1. **CLASSICAL MECHANICS — 20%**

(such as kinematics, Newton's laws, work and energy, oscillatory motion, rotational motion about a fixed axis, dynamics of systems of particles, central forces and celestial mechanics, three-dimensional particle dynamics, Lagrangian and Hamiltonian formalism, noninertial reference frames, elementary topics in fluid dynamics)

2. ELECTROMAGNETISM — 18%

(such as electrostatics, currents and DC circuits, magnetic fields in free space, Lorentz force, induction, Maxwell's equations and their applications, electromagnetic waves, AC circuits, magnetic and electric fields in matter)

3. OPTICS AND WAVE PHENOMENA — 9%

(such as wave properties, superposition, interference, diffraction, geometrical optics, polarization, Doppler effect)

4. THERMODYNAMICS AND STATISTICAL MECHANICS — 10%

(such as the laws of thermodynamics, thermodynamic processes, equations of state, ideal gases, kinetic theory, ensembles, statistical concepts and calculation of thermodynamic quantities, thermal expansion and heat transfer)

5. QUANTUM MECHANICS — 12%

(such as fundamental concepts, solutions of the Schrödinger equation (including square wells, harmonic oscillators, and hydrogenic atoms), spin, angular momentum, wave function symmetry, elementary perturbation theory)

6. ATOMIC PHYSICS — 10%

(such as properties of electrons, Bohr model, energy quantization, atomic structure, atomic spectra, selection rules, black-body radiation, x-rays, atoms in electric and magnetic fields)

7. SPECIAL RELATIVITY — 6%
(such as introductory concepts, time dilation, length contraction, simultaneity, energy and momentum, four-vectors and Lorentz transformation, velocity addition)

8. LABORATORY METHODS — 6%
(such as data and error analysis, electronics, instrumentation, radiation detection, counting statistics, interaction of charged particles with matter, lasers and optical interferometers, dimensional analysis, fundamental applications of probability and statistics)

9. SPECIALIZED TOPICS — 9%

Nuclear and Particle physics (e.g., nuclear properties, radioactive decay, fission and fusion, reactions, fundamental properties of elementary particles), Condensed Matter (e.g., crystal structure, x-ray diffraction, thermal properties, electron theory of metals, semiconductors, superconductors), Miscellaneous (e.g., astrophysics, mathematical methods, computer applications)

Those taking the test should be familiar with certain mathematical methods and their applications in physics. Such mathematical methods include single and multivariate calculus, coordinate systems (rectangular, cylindrical and spherical), vector algebra and vector differential operators, Fourier series, partial differential equations, boundary value problems, matrices and determinants, and functions of complex variables. These methods may appear in the test in the context of various content categories as well as occasional questions concerning only mathematics in the specialized topics category above.

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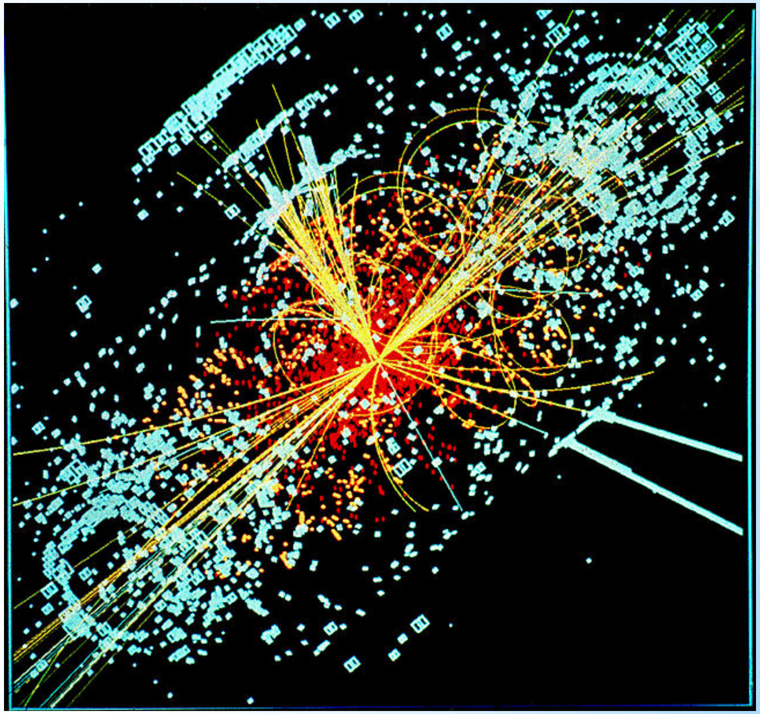


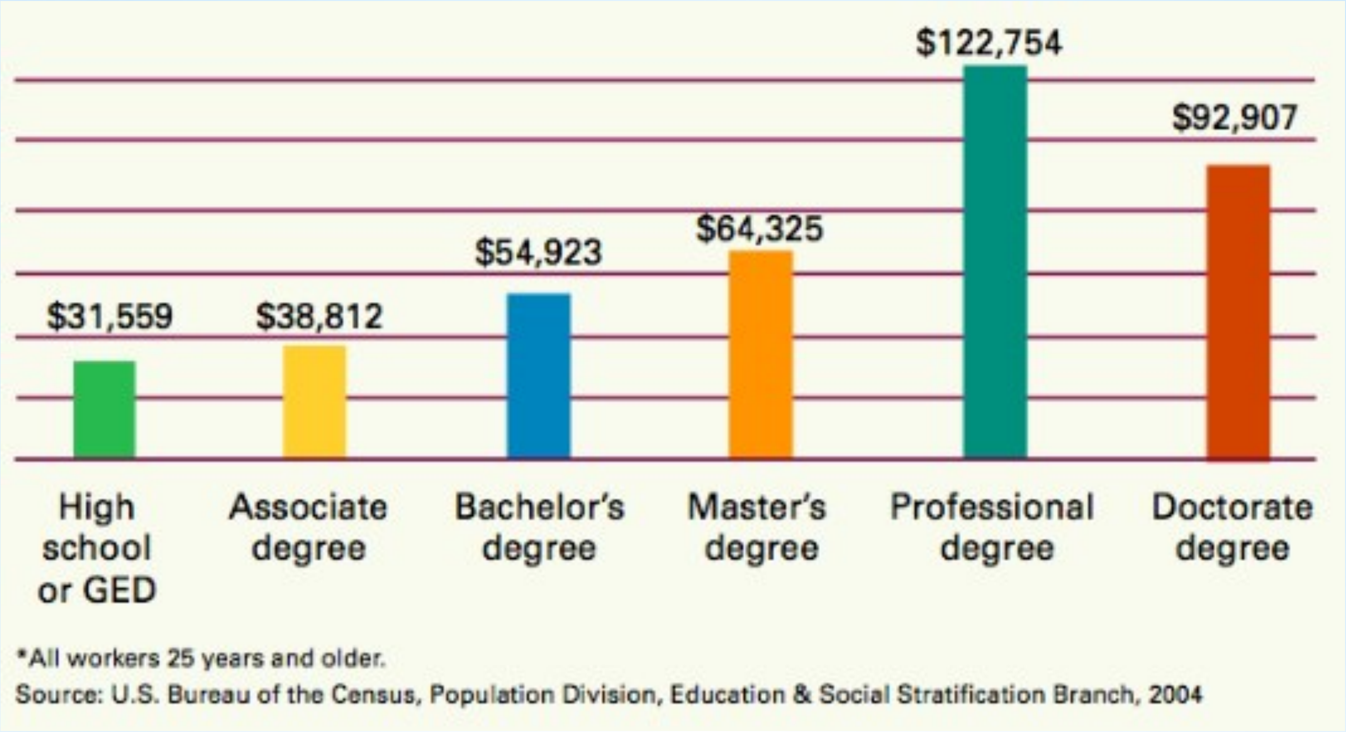
Can I afford to go to grad school?

As a PhD student, most universities have a policy on financial assistance that will typically allow you to go through your entire graduate program at no cost to you. The stipend (~$25 k) that goes along with graduate teaching or research assistantships is sufficient to provide for living expenses, but grad school is certainly not a way to build up your savings account. If you manage to obtain an outside fellowship, you will have the greatest possible freedom in your choice of PhD advisors and dissertation topics. Master's students generally don't get assistantships.

Working toward a PhD in physics is a full-time activity, so you shouldn't plan on supplementing your income with an additional job.

What can I do with an advanced degree?

Beyond becoming professional scientists, physics students pursuing advanced degrees learn how to solve new problems, especially using mathematical methods of modeling and analysis. The skills you get in an advanced physics degree are useful in any career that involves solving challenging problems, which is to say just about anything. Students with advanced physics degrees go on to a range of technical careers: research at national laboratories; industrial and technical research in fields ranging from semiconductor fabrication to lasers and optics to financial modeling to medicine; and, of course, research and teaching at universities. Average earning power is significantly higher with an advanced degree. The bar chart shows a comparison from 2003:



* *If you have the talent, can you afford <u>not</u> to go to grad school?*

What's it like to go to grad school?

Of course, the above benefits come with a cost: an advanced physics degree is one of the most challenging and intellectually demanding pursuits there is. You'll be expected to work hard, and often you'll spend long hours finishing up that quantum mechanics problem set or getting data ready right before that important conference. Not everyone is cut out for a Ph.D. in physics. But if you *are* up to the challenge, graduate school will be one of the most rewarding experiences of your life. There is nothing comparable to the high you get from finally getting your experiment to work or nailing a hard theoretical problem after months or years of effort. And your dissertation, if you put in the effort, will be something to be truly proud of.

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Limits imposed by ionizing radiation on the long-term survival of trapped bacterial spores: beta radiation

A. J. NICASTRO†*, R. H. VREELAND‡ and W. D. ROSENZWEIG‡

(Received 9 January 2002; accepted 10 May 2002)

Abstract.
Purpose: A model is presented for determining the survival time T_F of a fraction F of a population of bacterial spores trapped within a fluid inclusion and subject to genetic damage from beta radiation.
Methods: The limiting factor to survival is the production of double-strand breaks (DSB) in the DNA resulting from single-track cleaving and from the cumulative effects of single-strand breaks (SSB) induced by the presence of ionizing radiation in the environment. The model considers the probability that radicals and ions formed by the passage of high-energy particles will interact with a DNA molecule and induce damage.
Results: The survival time T_F for a fraction F of a trapped population is a weak function of both F and the length L in base pairs of the genome. For irradiation due to a beta source trapped with the spores within the inclusion, the survival time is also inversely proportional to the concentration of the radionuclide, the dominant factor in limiting survival time.
Conclusions: The predictions of the model are consistent with measured DSB formation rates, the observed survival of trapped spores over time periods as long as 250 Ma, and track structure models which address low physical dose rates.

1. Introduction

Some species and strains of bacteria (i.e. *Bacillus* and *Clostridium*) are able, when conditions are adverse, to enter a dormant spore state wherein metabolic activity functionally ceases. Such spores, trapped within crystal inclusions, may lie dormant for extended time periods, protected to some degree by the encasing crystal. Vreeland *et al.* (2000) revived a *Bacillus* species (strain 2-9-3) trapped in a halite fluid inclusion 600 m below the surface for 250 Ma (250 million years). Parkes (2000) comments that, given the care taken to avoid contamination, that study presents the best evidence for the extreme longevity possible in micro-organisms. A question naturally arises as to what limits the long-term survival of trapped bacteria. In this paper, the limits imposed by the presence of beta radiation on the survival of bacterial spores trapped within fluid inclusions of crystals is examined.

Bacterial spores trapped within a fluid inclusion are subject to exposure to ionizing radiation. This radiation may originate from radionuclides within the fluid, in the encasing crystal, or from crustal rock surrounding the crystal. This paper shows that the flux of alphas and of high-energy particles comprising cosmic rays is a negligible factor compared to the beta dose. The fact that Vreeland *et al.* (2000) were able to revive 250 Ma bacilli indicates that these organisms are rather robust, and that, at least in that case, the exposure was insufficient to kill all the trapped spores.

Lesions on a DNA molecule may be created by the near-passage of a high-energy particle such as might be emitted in radioactive decay. A direct collision of the particle with a constituent atom of the DNA may sever structural bonds by dislodging or ionizing the atom, or the high-energy particle can also create highly reactive radicals in the vicinity of a DNA strand which can subsequently attack critical sites on the molecule and sever structural bonds. The electric field of a relativistic particle is oriented so that the greatest field strength lies perpendicular to the particle's velocity (Jackson 1975). Passage of such a particle through a fluid produces ions several nanometers on either side of its trajectory (Turner 1995). If the fluid through which the particle moves has water as its dominant constituent, such as would be expected to be the case for bacterial DNA, ionizing radiation generally gives rise to H_2O^-, H_3O^+, OH, OH^- and some H_2O_2 and H_2. Some of these products are the result of radicals interacting with themselves (Ward 1988). Along with direct ionization, the action of these radicals formed by water radiolysis produces lesions and deformations in DNA.

2. Lethal damage to DNA

The most significant types of damage to DNA that can lead to cell death are recognized to be double-strand breaks (DSB) and the accumulation of

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Death roll of the alligator: mechanics of twist feeding in water

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Summary

Crocodilians, including the alligator (*Alligator mississippiensis*), perform a spinning maneuver to subdue and dismember prey. The spinning maneuver, which is referred to as the 'death roll', involves rapid rotation about the longitudinal axis of the body. High-speed videos were taken of juvenile alligators (mean length=0.29 m) performing death rolls in water after biting onto a pliable target. Spinning was initiated after the fore- and hindlimbs were appressed against the body and the head and tail were canted with respect to the longitudinal body axis. With respect to the body axis, the head and tail bending averaged 49.2° and 103.3°, respectively. The head, body and tail rotated smoothly and freely around their individual axes of symmetry at 1.6 Hz. To understand the dynamics of the death roll, we mathematically modeled the system. The maneuver results purely from conservation of angular momentum and is explained as a zero angular momentum turn. The model permits the calculation of relevant dynamical parameters. From the model, the shear force, which was generated at the snout by the juvenile alligators, was 0.015 N. Shear force was calculated to scale with body length to the 4.24 power and with mass to the 1.31 power. When scaled up to a 3 m alligator, shear force was calculated at 138 N. The death roll appears to help circumvent the feeding morphology of the alligator. Shear forces generated by the spinning maneuver are predicted to increase disproportionately with alligator size, allowing dismemberment of large prey.

Key words: death roll, alligator, *Alligator mississippiensis*, feeding, maneuverability.

Introduction

Crocodilians, including the American alligator *Alligator mississippiensis*, are large aquatic predators. These reptiles approach their prey with stealth and forcefully grab the prey with their conical teeth and large jaws (Davenport et al., 1990; Cleuren and De Vree, 1992; Cleuren and De Vree, 2000; Erickson et al., 2003). Although small prey are swallowed whole, large prey are subdued and dismembered with a spinning maneuver (McIlhenny, 1935; Neill, 1971; Guggisberg, 1972; Pooley and Gans, 1976; Ross, 1989). This maneuver is dramatically termed the 'death roll'. The death roll is an example of a behavioral strategy referred to more generally as rotational feeding.

Body-rolling inertial feeding or rotational feeding is used by elongate vertebrates that lack specialized cutting dentition (Gans, 1974; Helfman and Clark, 1986; Davenport et al., 1990; Maesey and Herrel, 2006). The inability to cut food into smaller portions requires such species to use mechanisms to remove manageable pieces from prey that are too large to consume whole. Large crocodiles and alligators will grab a limb or lump of flesh with their jaws and then rotate around the longitudinal axis of their body until the piece is torn free (Guggisberg, 1972; Cleuren and De Vree, 2000). While there have been numerous observations of the spinning behavior for prey reduction, there is only one description of the gross motions of the body components for the alligator (McIlhenny, 1935). McIlhenny reported that an alligator would immediately roll when it caught an animal that was too large to be instantly killed. The alligator would initiate the roll by throwing its tail up and sideways. The body and tail would turn simultaneously in the same direction. The feet were not used as they were folded against the body. Observations from a second crocodilian species, large (>3 m) Nile crocodiles, *Crocodylus niloticus*, reported spin rates of 0.55–1.11 rotations s^{-1} (Helfman and Clark, 1986).

The mechanics of the spinning maneuver in crocodilians have not been previously examined. The goal of this study was to understand how the alligator is able to initiate and sustain a spinning maneuver in an aquatic medium and to construct a model to describe the relevant dynamics. In this study, we were able to elicit juvenile alligators in the laboratory to spin in the manner of the death roll. By using high-speed video recordings of the rolling maneuver, we detailed the movements of body components and measured spinning performance. From this information, a mathematical model was produced that satisfactorily described the dynamics of the rolling maneuver, allowing the model to predict the torque and shear forces produced at the snout during this feeding behavior.

Materials and methods

Nine juvenile alligators *Alligator mississippiensis* Daudin were purchased from a commercial alligator farm (Everglades Outpost, Homestead, FL, USA). Each alligator was weighed,

$$S = \frac{0.412}{\rho} E^{0.37 - \text{[illegible]} \ln E} \left(\frac{1.8 \times 10^{-4}\,\text{MeV}}{1\ \text{structure}} \right) \tag{13}$$

phosphodiester moiety always results in a SSB. Finally, the probability that a randomly emitted particle will pass a DNA molecule and induce a SSB is

$$P_{\text{SSB}} = \frac{2(\lambda + 1\,\text{nm})}{4\pi^2 (\frac{3}{4} V_{\text{inc}}^{1/3})^2} L \left(\frac{3.4\,\text{nm}}{10\ \text{base pairs}} \right) \times \frac{2}{S} \left(\frac{5\,\text{nm}^2}{(\lambda + 1\,\text{nm})} \right) \frac{1}{2.7} \tag{17}$$

Solving this expression for T_F yields

$$T_F = \frac{t_{1/2}}{\ln 2} \left[\frac{S N_{\text{SSB}} M}{(1.12 \times 10^{-19}\,\text{mm}^3) C V_{\text{inc}}^{1/3} N_A L} \right] = \frac{t_{1/2}}{\ln 2} \left[-\frac{4 \ln F}{2b + 1} \right]^{1/2} \times \left[\frac{SM}{(1.12 \times 10^{-19}\,\text{mm}^3) C V_{\text{inc}}^{1/3} N_A L^{1/2}} \right] \tag{21}$$

where used again is the Taylor series expansion $\ln(1 + x) \approx x$, for x small compared to 1.

number. Thus, for a fluid of density ρ (in g/mm^3) within the inclusion, the dose will be

$$D = \frac{C V_{\text{inc}} N_A}{M} \{\exp[(\ln 2)t/t_{1/2}] - 1\}(9.37 \times 10^{-14})\,\text{J} = \frac{C N_A}{M\rho} \{\exp[(\ln 2)t/t_{1/2}] - 1\}(9.37 \times 10^{-8})\,\text{Gy} \tag{22}$$

where now ρ is in g/cm^3. For a DSB rate of 10^{-2} DSB Gy^{-1} Mbp^{-1} $= (10^{-8}$ DSB Gy^{-1} bp$^{-1})L$, the number of single-track DSB is given by

$$N_{\text{DSB, single-track}}^{K-40} = \frac{C N_A L}{M\rho}(9.37 \times 10^{-16}) \times \{\exp[(\ln 2)t/t_{1/2}] - 1\} \tag{23}$$

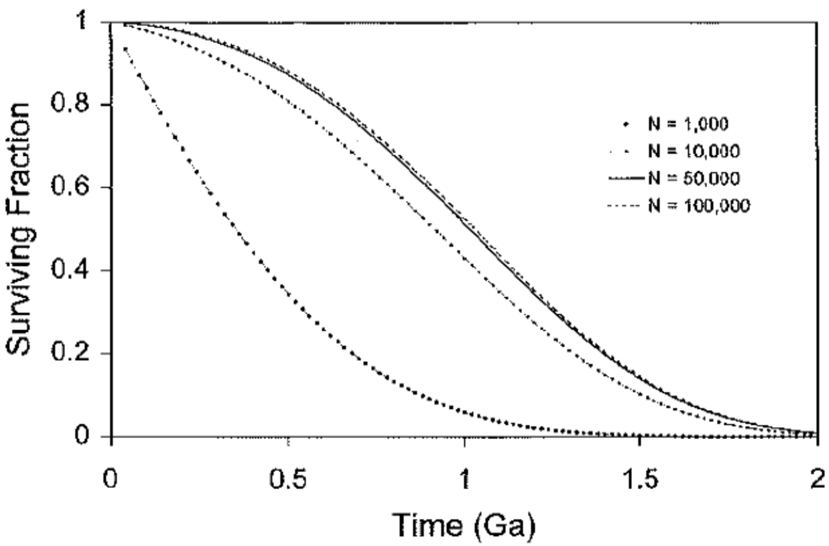

Figure 5. The dependence of the surviving fraction of spores on the number of trapped individuals. For populations exceeding about 50 000 individuals, the surviving fraction is nearly independent of the number of spores initially trapped within the inclusion. For these calculations, $b = 2.64$ and the concentration of ${}^{40}_{19}K$ is 6.5×10^{-11} g/mm^3.

The efficacy of the model may also be compared with measured rates of induced damage to DNA. Newman *et al.* (1997) irradiated Chinese hamster V79 cells with alphas from ^{238}Pu which possessed an incident energy at the cells of 3.5 MeV and corresponded to an LET of 110 keV/μm. The range of these alphas within the cell is 31.8 μm, and using equation 11 the average distance S between energy deposition structures is 1.6×10^{-6} mm. From the authors' model, the number of SSB induced per Gy per bp is given by equation 20 divided by equation 22 and divided by L, i.e.

$$(1.12 \times 10^{-19}\,\mathrm{mm}^3) V_{\mathrm{inc}}^{1/3} \rho / S,$$

which for this case is 5.7×10^{-6} SSB Gy^{-1} bp^{-1}. Table 1 indicates that, depending on the size of the genome, b, and the surviving fraction of spores, roughly 2000 SSB need to accumulate so as to form a DSB. The 4% contribution of single-track DSB is not significant at this level of approximation. Thus, we expect a DSB formation rate of approximately 3×10^{-9} DSB Gy^{-1} bp^{-1}. This rate agrees with the value of $3.15 \pm 0.29 \times 10^{-9}$ DSB Gy^{-1} bp^{-1} for alphas measured by Newman *et al.* (1997) using the distribution size method (Lehmann and Ormerod 1970). This agreement is, to some extent, fortuitous and coincidental, for the present model would have predicted values a factor of 2 higher and lower than this depending on the values of b, L, and F. Using the model of Cook and Mortimer (1991), Newman *et al.* (1997) find for alphas that the breakage frequencies ranged from $4.5 \pm 0.8 \times 10^{-9}$ DSB Gy^{-1} bp^{-1} for fragments with a mean weight of 5 Mbp to $633 \pm 140 \times 10^{-9}$ DSB Gy^{-1} bp^{-1} for fragments of 14 kbp mean weight. The agreement with the present authors' model is still satisfying.

*Death Roll of a Crocodile

major axis of a_H and semi-minor axes each of length b_H, we denote the smallest moment of inertia about the major axis as i_H. The moments about the two equal minor axes are each denoted by I_H and are larger than the moment about the major axis (Table 1). The length of the head l_H is $2a_H$ and the width and thickness are each $2b_H$. In this case,

$$i_H = \frac{m_H}{5}(b_H^2+b_H^2) = \frac{m_H}{5}(2b_H^2) \quad (1)$$

and

$$I_H = \frac{m_H}{5}(a_H^2+b_H^2)\,, \quad (2)$$

where m_H is the mass of the head alone (Gray, 1963). Similarly for the model ellipsoidal body (or trunk) with axes of length a_B and b_B, the principal moments of inertia i_B and I_B are given by:

$$i_B = \frac{m_B}{5}(b_B^2+b_B^2) = \frac{m_B}{5}(2b_B^2) \quad (3)$$

and

$$I_B = \frac{m_B}{5}(a_B^2+b_B^2)\,. \quad (4)$$

For the model right circular cone tail, the three principal moments are i_T and I_T given by:

$$i_T = \frac{3}{10}m_T r^2 \quad (5)$$

and

$$I_T = \frac{3}{20}m_T\left(r^2+\frac{l_T^2}{4}\right), \quad (6)$$

where m_T is the mass of the tail, r is its radius at the base, and l_T is its length.

The model head, body and tail all roll without slipping with angular speeds $\omega_H=\omega_B=\omega_T=\omega$ and simultaneously revolve around the RR′-axis, the roll axis, with angular speed ω_{rev} (Fig. 5).

The rotating head, body and tail each possess angular momentum. To determine the moments of inertia of the body parts and the resulting angular momenta about the RR′-axis, we adopt the coordinate system shown in Fig. 5. The unit vectors for each body part are described in Cartesian coordinates of $\hat{x}$ and $\hat{y}$. The $\hat{y}$ axes lie along the spin axes of each body part and the $\hat{x}$ axes are perpendicular to the $\hat{y}$ axes. The angular momentum of the head is:

$$\vec{L_H} = i_H\omega\hat{y}_H - i_H\omega_{rev}\cos\theta\hat{y}_H + I_H\omega_{rev}\sin\theta\hat{x}_H\,. \quad (7)$$

Similarly, for the body and tail, respectively,

$$\vec{L_B} = -i_B\omega\hat{y}_B - (i_B+m_Bd^2)\omega_{rev}\hat{y}_B\,, \quad (8)$$

$$\vec{L_T} = i_T\omega\hat{y}_T - i_T\omega_{rev}\cos\phi\hat{y}_T - I_T\omega_{rev}\sin\phi\hat{x}_T\,. \quad (9)$$

The parallel axis theorem was used to determine the moment of inertia of the body revolving around the RR′-axis, which is a distance d away from the longitudinal axis of the body.

In a zero angular momentum maneuver, the vector sum of these angular momenta vanishes, that is, $\vec{L_H}+\vec{L_B}+\vec{L_T}=0$. For this case,

$$0 = \omega_{rev}(I_H\hat{x}_H\sin\theta - I_T\hat{x}_T\sin\phi) + \omega(i_H\hat{y}_H+i_T\hat{y}_T) + \omega i_B\hat{y}_B - \omega_{rev}(i_H\hat{y}_H\cos\theta+i_T\hat{y}_T\cos\phi) - \omega_{rev}(i_B+m_Bd^2)\hat{y}_B\,. \quad (10)$$

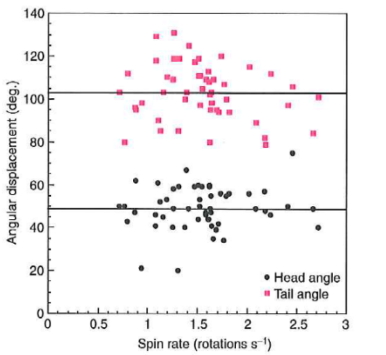

Fig. 4. Angular displacement of head and tail to symmetry axis of body in relation to spin rate. Solid lines indicate mean angles for the head and tail.

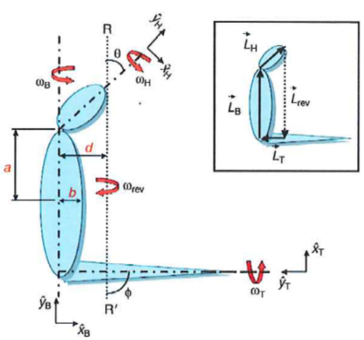

Fig. 5. Model of alligator during spinning maneuver. The head and tail are modeled as ellipsoids with circular cross sections. The tail is modeled as a elongate right circular cone. The semi major (a) and semi minor (b) axes of ellipsoids are exemplified on the body. Angular displacements of the head (θ) and tail (φ) are shown relative to the symmetry axis of the body. Angular velocities (ω_H, ω_B, ω_T) of body parts rotate together. The local Cartesian coordinate system is illustrated along the symmetry axis for each body part. The roll axis (RR′) is indicated by the broken line at a distance (d) from the symmetry axis of the body. The angular velocity (ω_{rev}) around the roll axis is opposite in direction to the angular velocities of the body parts. The inset illustrates the vector angular momenta for the entire system. The vector sum of the angular momenta is zero for the motions of the alligator during the spinning maneuver.

If the total angular momentum of a system is zero, it is zero about any axis. The angular momentum projected onto the RR′-axis is therefore:

$$0 = \omega_{rev}(I_H\sin^2\theta - I_T\sin^2\phi) + \omega(i_H\cos\theta+i_T\cos\phi) + \omega i_B - \omega_{rev}(i_H\cos^2\theta+i_T\cos^2\phi) - \omega_{rev}(i_B+m_Bl_H^2\sin^2\theta)\,, \quad (11)$$

where we have used the fact that $d=l_H\sin\theta$ with l_H the length of the head. After rearranging terms to form the ratio ω/ω_{rev}, we find:

$$\omega/\omega_{rev} = \frac{i_H\cos^2\theta + i_T\cos^2\phi + (m_Bl_H^2 - I_H)\sin^2\theta + I_T\sin^2\phi + i_B}{i_H\cos\theta + i_T\cos\phi + i_B}\,. \quad (12)$$

However, for θ=45° and ϕ=90°, which are typical values for these angles (Fig. 4), this expression reduces to:

$$\omega/\omega_{rev} = \frac{i_H + 2i_B + m_Bl_H^2 - I_H - 2I_T}{\sqrt{2}i_H + 2i_B}\,. \quad (13)$$

This expression is consistent with the observed characteristics of the death roll (see below).

It is important to note that the ω_{rev} motion (i.e. the motion of the animal revolving around the RR′-axis) is a reaction to the rolling motions initiated by the animal after it fastens onto its prey. Before the spin is initiated the angular momentum of the alligator is observed to be zero, must remain zero during the spin, and is observed to be zero when the spin terminates. The motion around the RR′-axis, which occurs at an angular frequency approximately an order of magnitude slower than the rolling motions, results purely from the conservation of angular momentum. This is roughly analogous to how a figure skater controls spin rate (Giancoli, 1985). By voluntarily bringing both arms close to his or her body from an extended position, a figure skater can increase angular speed to conserve angular momentum. Rather than this one-dimensional case, the death roll is a two-dimensional example.

Discussion

Significance of prey inertia to crocodilian spin feeding

Spinning is a maneuver to reduce large prey to small enough pieces that a crocodilian can swallow (McIlhenny, 1935; Neill, 1971; Guggisberg, 1972; Pooley and Gans, 1976; Ross, 1989). The conical teeth of crocodilians are useful for grasping prey with a large bite force (Erickson et al., 2003), but not for tearing and cutting flesh (Guggisberg, 1972). Spinning is a mechanism that can tear apart large prey by subjecting the tissue to torsional stresses. Animals and their tissues are weak in torsion (Gordon, 1978; Currey, 2002). The spinning maneuver is used predominately by crocodilians with broad, short snouts, which feed on large prey and on a more general diet (Cleuren and De Vree, 2000). This skull structure can resist the substantial forces associated with the maneuver (Cleuren and De Vree, 1992). Inertia of the prey is required for the maneuver to be effective. Spinning does not work with small prey animals, because as the crocodile spins, the prey will also rotate. Thus, when groups of crocodilians (e.g. *Crocodylus niloticus*) feed on a carcass at the same time (Pooley and Gans, 1976; Guggisberg, 1972; Ross, 1989), the inertia added by attached predators would facilitate the success of spin feeding by individual crocodilians by helping to secure the prey.

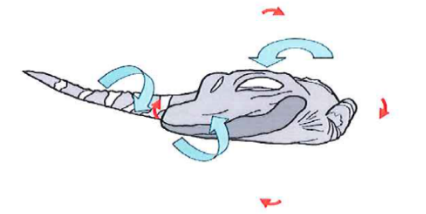

Fig. 6. Schematic of spinning motions. Blue arrows indicate directions of rotation of head, body and tail segments. Red arrows indicate compensatory rotation of the entire system. The relative size of the arrows illustrates a reduced rate of rotation of the compensatory spin compared to the rotation rates of the head, body and tail segments.

We discovered that juvenile alligators are capable of performing the death roll. Previous reports of spinning were associated with large crocodilians subduing or dismembering large prey items (McIlhenny, 1935; Pooley and Gans, 1976). Hatchling (50 g) and juvenile (100–550 g) salt-water crocodiles (*Crocodylus porosus*) feeding on carrion were observed to use side-to-side head shaking, rather than spinning, to detach small pieces (Davenport et al., 1990). Side-to-side head shaking was used to detach small pieces of the carrion. However, the carrion was a large fish, which may not have offered resistance to tearing (Davenport et al., 1990). The toughness of the food presented to the alligators in this study provided sufficient resistance to initiate the spinning behavior.

Conservation of angular momentum in crocodilian death rolls

The ferocity of the death roll of alligators and crocodiles is particularly enhanced by the rapid speed of the spinning motions. How can the animal generate these motions and still conserve angular momentum? From a configuration where the symmetry axes of the head, body and tail are all aligned, the animal quickly bends itself into a C-shape and commences spinning. Consequently, each body part possesses a vector angular momentum (Fig. 5). While the horizontal components of the angular momenta of the head and tail largely cancel, the vertical components add. This angular momentum vector, however, is canceled by a more subtle motion of the entire animal. As a reaction to the spinning motion, the animal also revolves around a roll axis roughly parallel to the animal's trunk (body). The roll axis runs through its snout, which is fastened onto meat, and a point approximately one-quarter of the distance from base of the tail to its tip. The revolution of the animal's head, body and tail about the roll axis also has an angular momentum, which is directly opposite to the vector sum of the angular momentums of each body segment. Thus, the initial angular momentum is zero, the total angular momentum during the roll is zero, and when the maneuver terminates by the alligator straightening, it remains zero.

The reason that the motion about the roll axis is less apparent than the spinning motions of the head, body and tail is because

If the total angular momentum of a system is zero, it is zero about any axis. The angular momentum projected onto the RR′-axis is therefore:

$$0 = \omega_{rev}(I_H \sin^2\theta - I_T \sin^2\phi) + \omega(i_H \cos\theta + i_T \cos\phi) + \omega i_B - \omega_{rev}(i_H \cos^2\theta + i_T \cos^2\phi) - \omega_{rev}(i_B + m_B l_H^2 \sin^2\theta)\,, \quad (11)$$

where we have used the fact that $d = l_H \sin\theta$ with l_H the length of the head. After rearranging terms to form the ratio ω/ω_{rev}, we find:

$$\omega/\omega_{rev} = \frac{i_H \cos^2\theta + i_T \cos^2\phi + (m_B l_H^2 - I_H)\sin^2\theta + I_T \sin^2\phi + i_B}{i_H \cos\theta + i_T \cos\phi + i_B}\,. \quad (12)$$

However, for $\theta = 45°$ and $\phi = 90°$, which are typical values for these angles (Fig. 4), this expression reduces to:

$$\omega/\omega_{rev} = \frac{i_H + 2i_B + m_B l_H^2 - I_H - 2I_T}{\sqrt{2} i_H + 2i_B}\,. \quad (13)$$

This expression is consistent with the observed characteristics of the death roll (see below).

It is important to note that the ω_{rev} motion (i.e. the motion of the animal revolving around the RR′-axis) is a reaction to the rolling motions initiated by the animal after it fastens onto its prey. Before the spin is initiated the angular momentum of the alligator is observed to be zero, must remain zero during the spin, and is observed to be zero when the spin terminates. The motion around the RR′-axis, which occurs at an angular frequency approximately an order of magnitude slower than the rolling motions, results purely from the conservation of angular momentum. This is roughly analogous to how a figure skater controls spin rate (Giancoli, 1985). By voluntarily bringing both arms close to his or her body from an extended position, a figure skater can increase angular speed to conserve angular momentum. Rather than this one-dimensional case, the death roll is a two-dimensional example.

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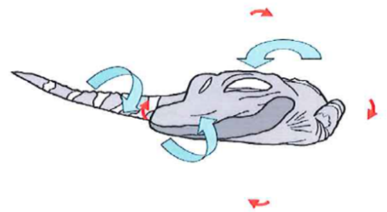

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What do I need to do before applying to grad school?

Study for the physics GRE. This will help improve your chance of getting admitted. However, in studying for this exam, remember that passing the GRE is only one of many criteria for success in grad school, and therefore a bad score won't sink your application if the rest is good. Don't study for the test alone (i.e., by doing practice tests): try to use the GRE preparation as a time of in-depth review, because that will go a long way towards mastering the qualifying examinations required by many departments.

How do I go about applying to grad school?

The official application deadline at most Physics Departments falls in January or February, so you should aim to submit your application in December. You should talk to professors about writing you recommendation letters *before* the end of Fall semester. Also, write a letter of intent to accompany your application, summarizing in about 500 words how you see graduate studies mesh with your prior experience and career goals. The process of doing this can be valuable in itself since it leads you to identify areas of interest and perhaps also directions you'd like to avoid going into.

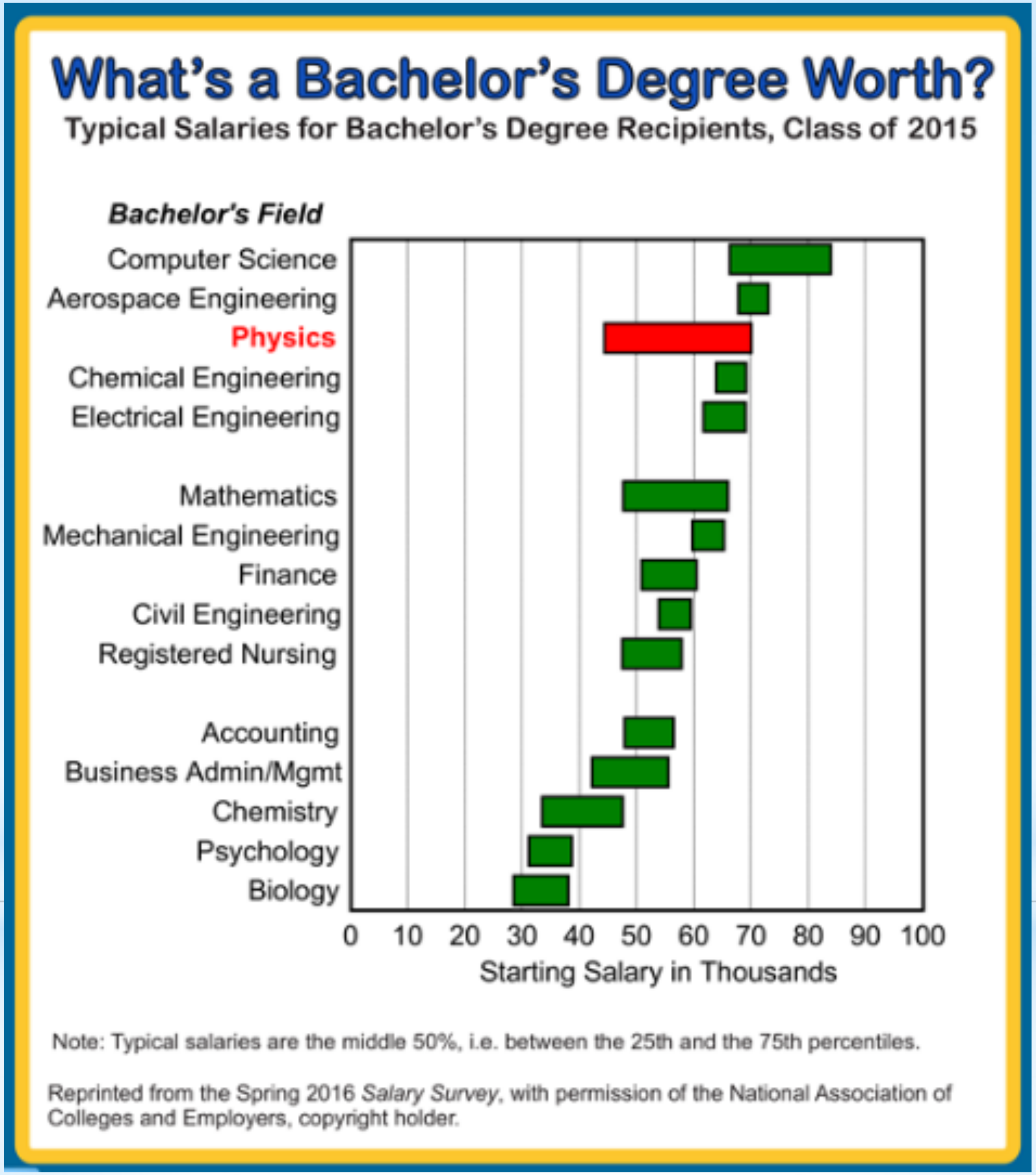
You have the Faculty's best wishes for success …
regardless of the path you take!

* Futures in Physics

What are the opportunities open to me when I graduate?

* http://www.aip.org/career-resources

An Important Resource


What's a Bachelor's Degree Worth?
Typical Salaries for Bachelor's Degree Recipients, Class of 2015
Bachelor's Field
Computer Science
Aerospace Engineering
Physics
Chemical Engineering
Electrical Engineering
Mathematics
Mechanical Engineering
Finance
Civil Engineering
Registered Nursing
Accounting
Business Admin/Mgmt
Chemistry
Psychology
Biology
0 10 20 30 40 50 60 70 80 90 100
Starting Salary in Thousands
Note: Typical salaries are the middle 50%, i.e. between the 25th and the 75th percentiles.
Reprinted from the Spring 2016 *Salary Survey*, with permission of the National Association of Colleges and Employers, copyright holder.

Initial Outcomes of Physics Bachelors, Classes of 2013 & 2014 Combined

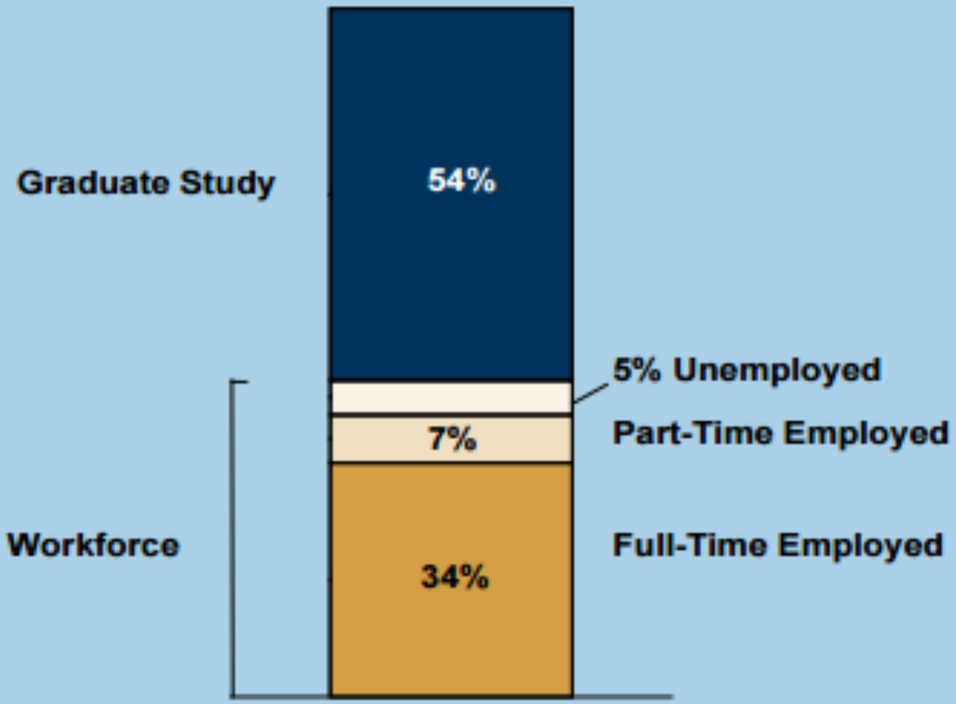
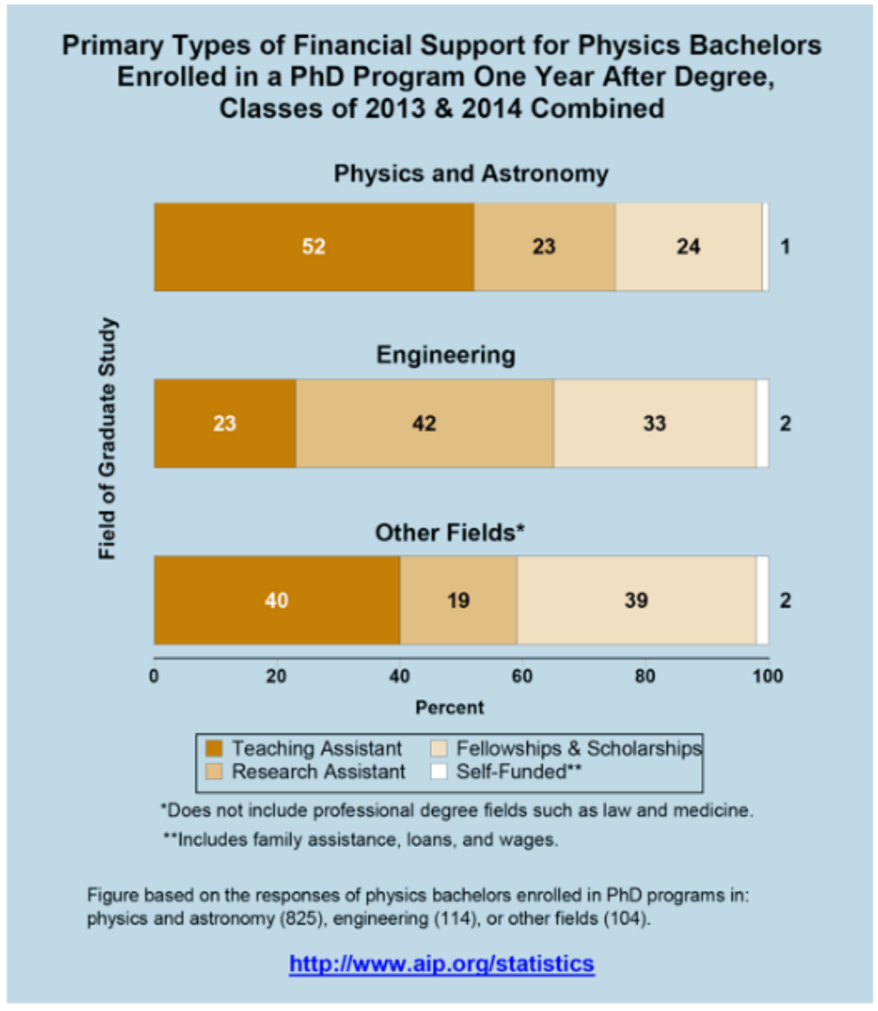


Figure based on the responses of 4,886 individuals

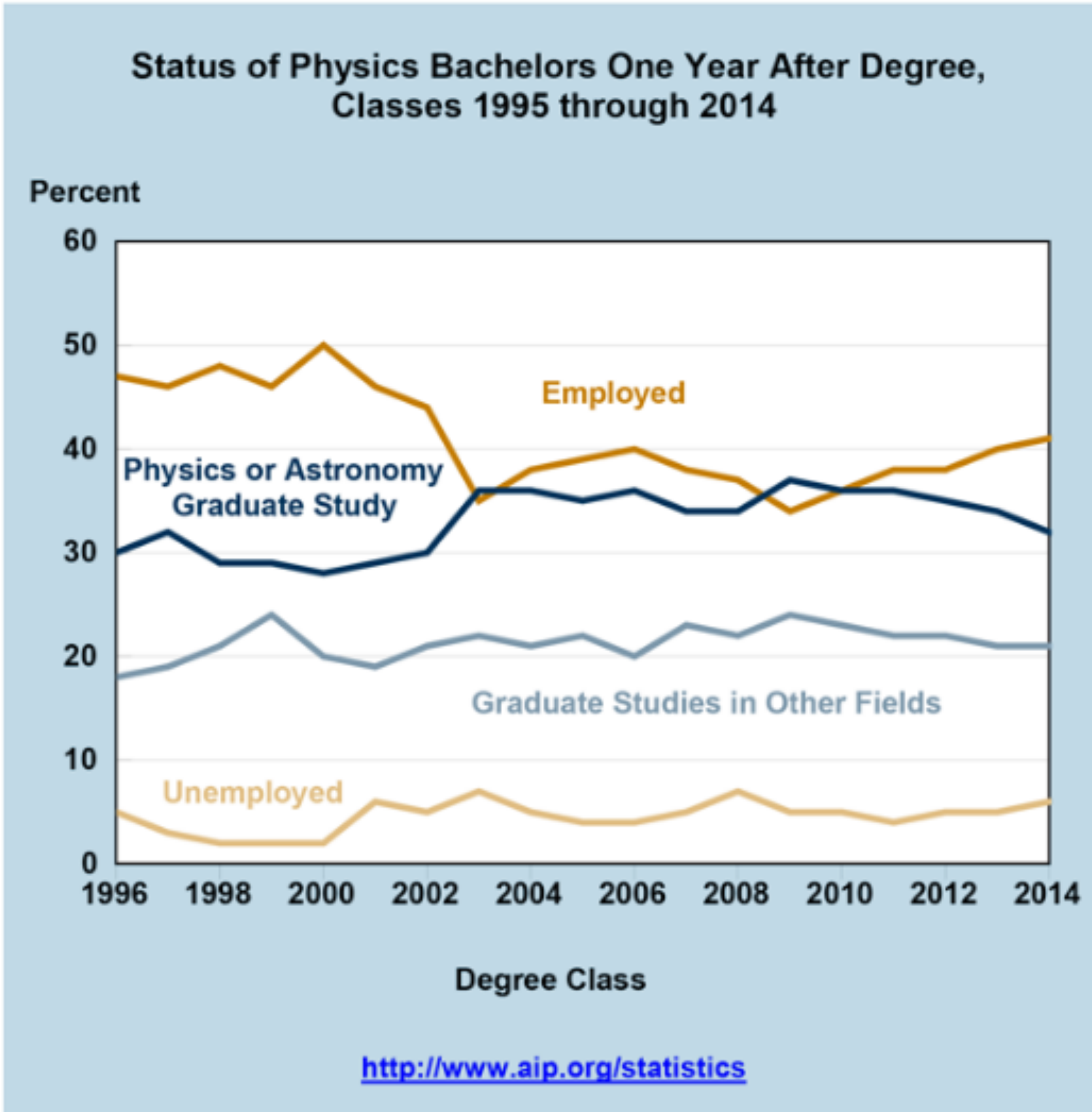
www.aip.org/statistics

There are good reasons not to go to graduate school.

Money is not one of them!

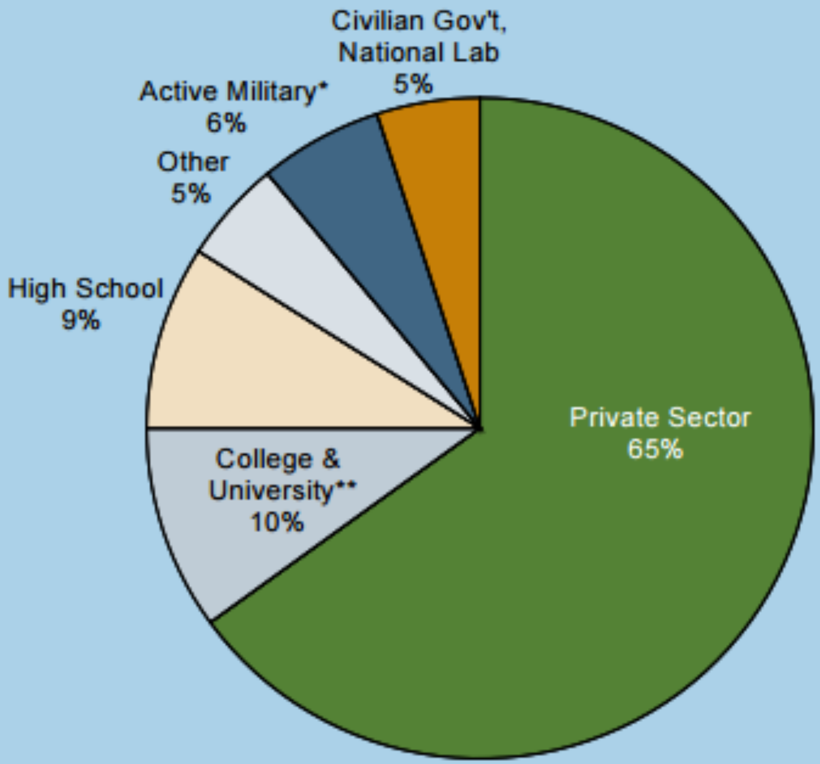


Virtually all physics bachelor's enrolled in a PhD program are financially supported, regardless of field.



Status of Physics Bachelors One Year After Degree,
Classes 1995 through 2014
Percent
60
50
40
30
20
10
0
Employed
Physics or Astronomy Graduate Study
Graduate Studies in Other Fields
Unemployed
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Degree Class
http://www.aip.org/statistics

Initial Employment Sectors of Physics Bachelors, Classes of 2013 & 2014 Combined



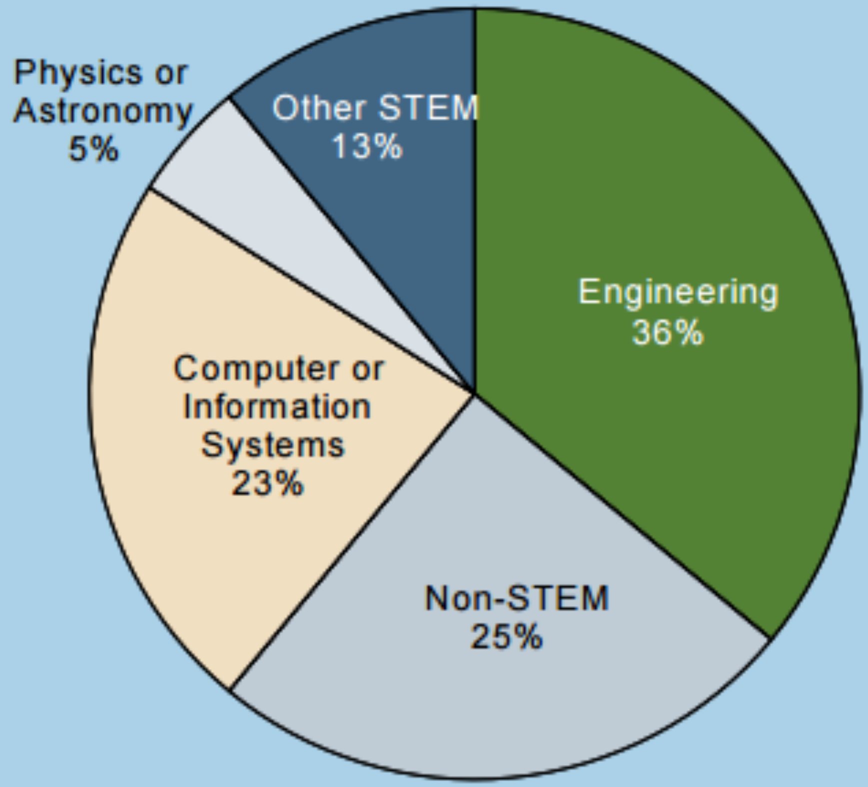
*Data do not include degree recipients from the three military academies (US Naval Academy, US Military Academy, US Air Force Academy).

** Data include two- and four-year colleges, universities, and university affiliated research institutes.

Figure based on the responses of 1,657 individuals

www.aip.org/statistics

Field of Employment for Physics Bachelors in the Private Sector, Classes of 2013 & 2014 Combined



STEM refers to natural science, technology, engineering, and mathematics.

Figure is based on 1,141 responses

www.aip.org/statistics

Job Titles of Positions filled by Physics Graduates with Bachelor Degrees

Engineering

- Systems Engineer
- Electrical Engineer
- Design Engineer
- Mechanical Engineer
- Project Engineer
- Optical Engineer
- Manufacturing Engineer
- Manufacturing Technician
- Laser Engineer
- Associate Engineer
- Application Engineer
- Development Engineer
- Engineering Technician
- Field Engineer
- Process Engineer
- Process Technician
- Product Engineer
- Product Manager
- Research Engineer
- Test Engineer
- General Engineer
- Technical Services Engineer

Computer Hardware / Software

- Software Engineer
- Programmer
- Web Developer
- IT Consultant
- Systems Analyst
- Technical Support Staff
- Analyst

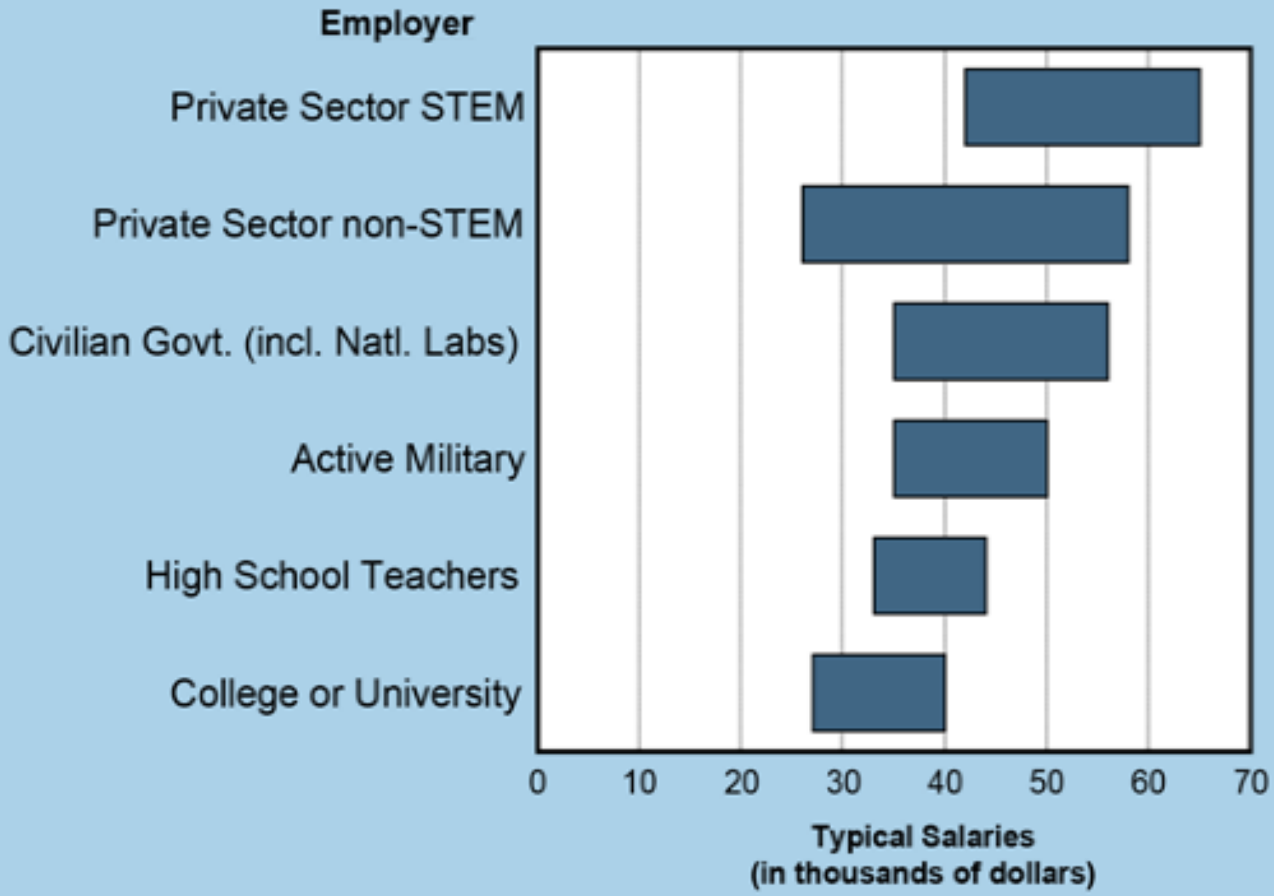
Education

- High School Physics Teacher
- High School Science Teacher
- Middle School Science Teacher

Research and Technical

- Research Assistant
- Research Associate
- Research Technician
- Lab Technician
- Lab Assistant
- Accelerator Operator
- Physical Sciences Technician

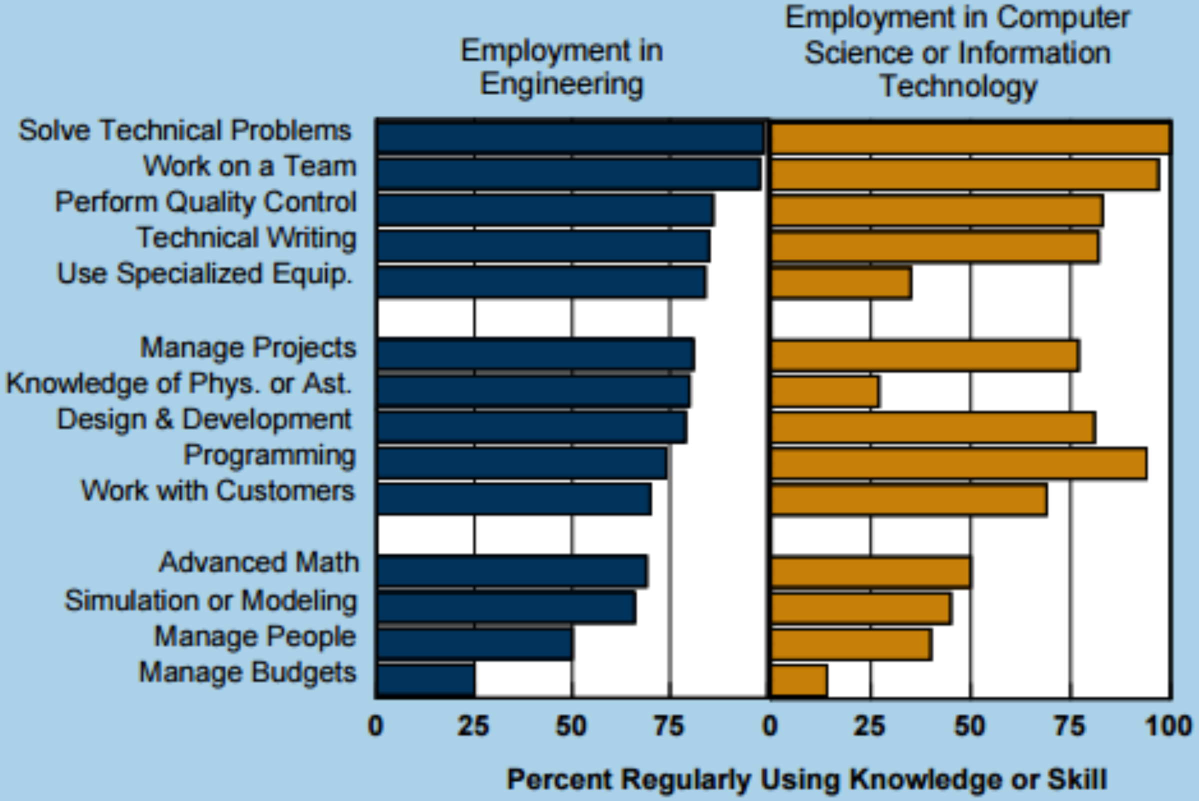
Typical Starting Salaries for Physics Bachelors, Classes of 2013 & 2014 Combined



This figure includes only bachelors in full-time, newly accepted positions. Typical salaries are the middle 50% i.e. between the 25th and 75th percentiles. STEM refers to positions in natural science, technology, engineering, and math. Data are based on respondents holding potentially permanent jobs in private sector STEM positions (498), private sector non-STEM positions (114), civilian government positions (52), the active military (44), high school teaching positions (82), and universities or colleges (84).

www.aip.org/statistics

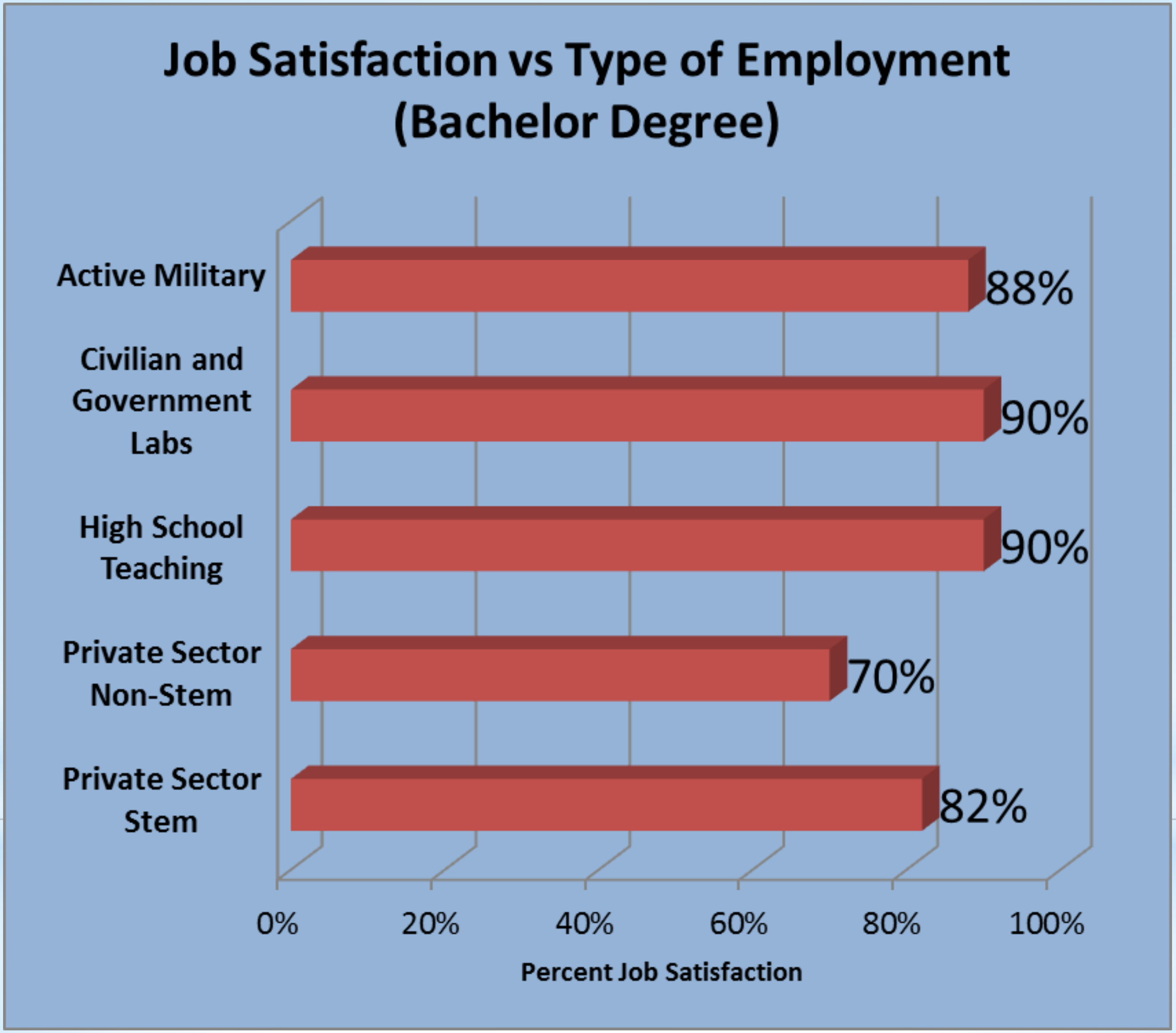
Knowledge and Skills Regularly Used by Physics Bachelors Employed in the Private Sector, Classes of 2013 & 2014 Combined



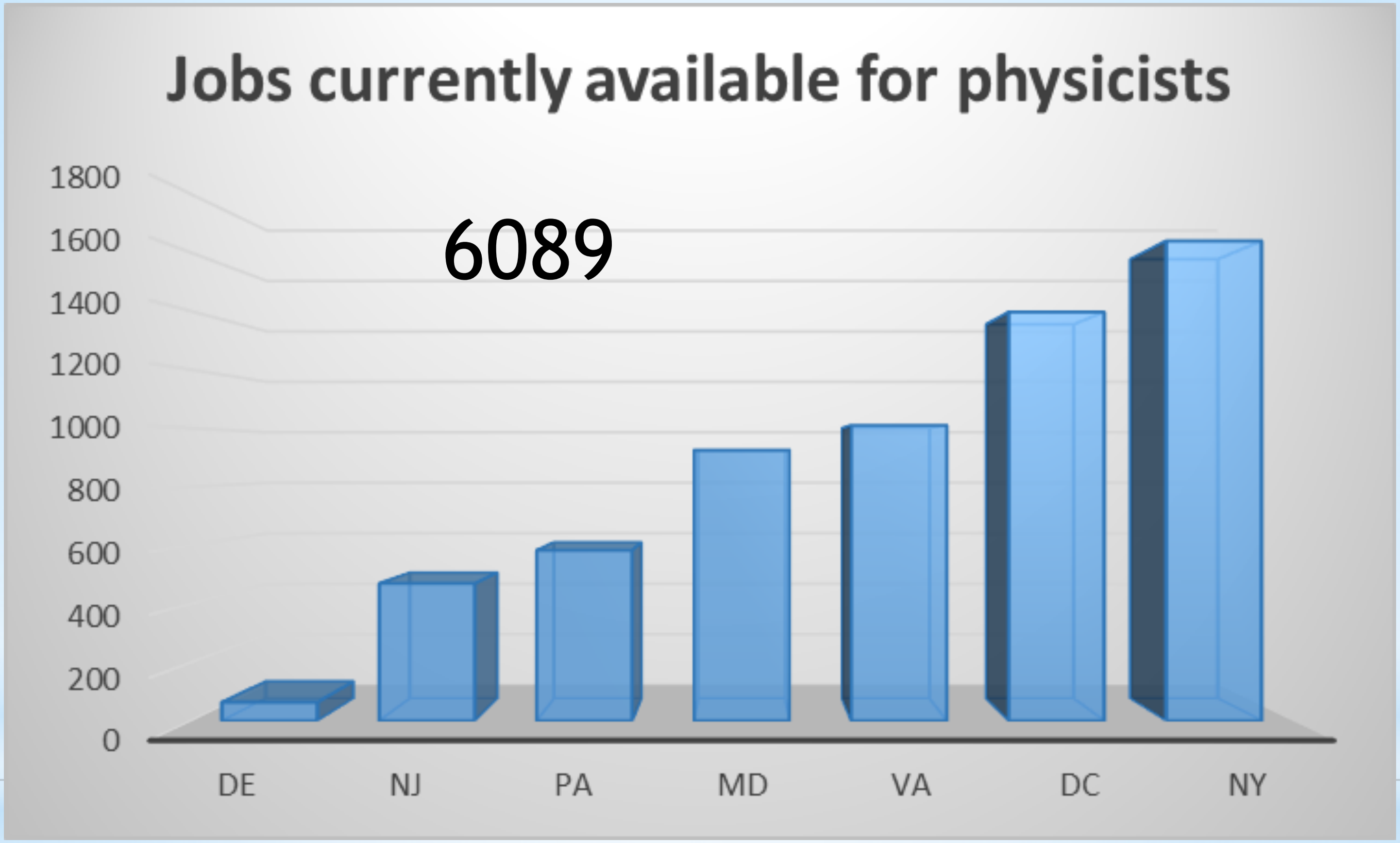
Percentages represent the physics bachelors who chose "daily," "weekly," or "monthly" on a four-point scale that also included "never or rarely."

Figure based on the responses of 287 physics bachelors employed in private sector engineering positions and 215 physics bachelors employed in private sector computer science positions.

www.aip.org/statistics



Source: AIP Statistical Research Center



Source: www.indeed.com
September 21, 2017

SPS JOBS

The SPS web site currently list

200 jobs

For Bachelor Degree Physicists

http://jobs.spsnational.org/jobs/

What do employers look for?

- Experience
  - Do you have equipment experience
  - Do you know how to think on your own
  - Can you think outside the box
    - How do I get this experience while I am in school?
      - 310 & 320 Lab Courses
      - Student Faculty Research Project

* Strong References:
  * Research Advisor
  * Teachers
  * Employers (if you have worked while in school)
* How do I get good references?
  * Of course work hard but
  * Just as important get to know us and let us get to know you.

* What do employers look for?

* Good writing skills:
  * This is a must, you will be writing all the time!
  * How do I get these,
    * Practice, Practice, Practice
    * If you can’t write well, get help now while you are here.
      * Use the University Writing Center.
      * Take a writing course.
      * Practice, Practice, Practice

*What do employers look for?

What do employers look for?

* Good GPA
  * Experience and a good work ethic will carry you a long way
    * But the better your GPA the better your chances for a good job.
  * An excellent GPA may not be essential but *"it can't hurt"*
  * A weak GPA will hurt!

*Thank You

Questions?