Applied Physics Seminar:

2018 Nobel Prize in applied Physics

“for groundbreaking inventions in the field of laser physics"

https://www.nobelprize.org/prizes/physics/2018/summary/

Ill. Niklas Elmehed. © Nobel Media

Arthur Ashkin

Prize share: 1/2

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Gérard Mourou

Prize share: 1/4

Ill. Niklas Elmehed. © Nobel Media

Donna Strickland

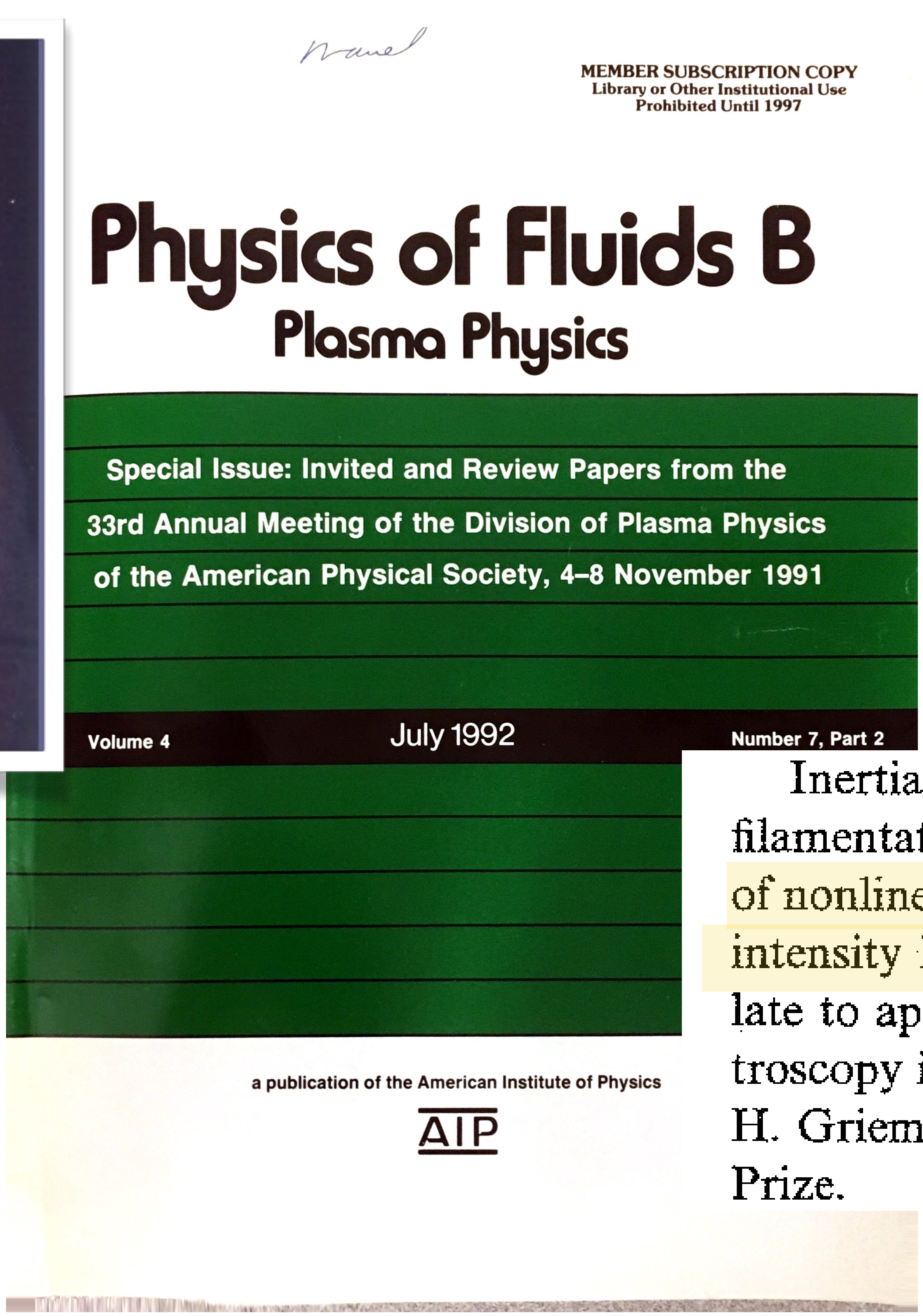
Prize share: 1/4

Outline

- Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses."
- Arthur Ashkin "for the optical tweezers and their application to biological systems"
- Ashkin's influence on David Wineland and ion-trap quantum computer
- Q-Computing in the news:
    - Graduate Student, Urmila Mahadev, Solves Quantum Verification Problem
    - D-Wave is offering public/cloud access to it's quantum computer

33rd Annual Division of Plasma Physics/American Physical Society (DPP/APS) Meeting, Tampa, FL, 4-8 Nov. 1991.

Prof. Abe Bers (MIT)
1930-2015



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Physics of Fluids B
Plasma Physics

Special Issue: Invited and Review Papers from the
33rd Annual Meeting of the Division of Plasma Physics
of the American Physical Society, 4–8 November 1991

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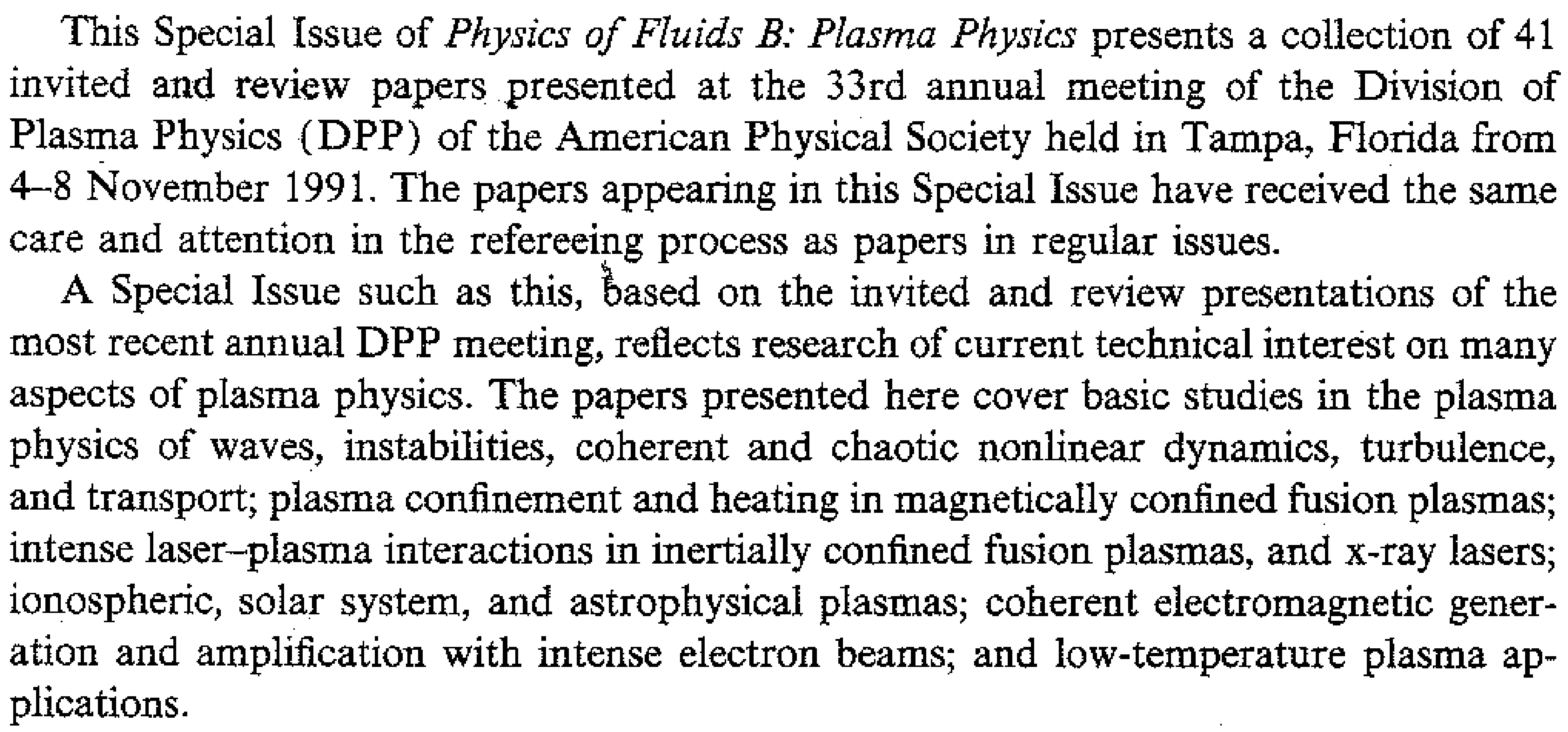

This Special Issue of *Physics of Fluids B: Plasma Physics* presents a collection of 41 invited and review papers presented at the 33rd annual meeting of the Division of Plasma Physics (DPP) of the American Physical Society held in Tampa, Florida from 4–8 November 1991. The papers appearing in this Special Issue have received the same care and attention in the refereeing process as papers in regular issues.

A Special Issue such as this, based on the invited and review presentations of the most recent annual DPP meeting, reflects research of current technical interest on many aspects of plasma physics. The papers presented here cover basic studies in the plasma physics of waves, instabilities, coherent and chaotic nonlinear dynamics, turbulence, and transport; plasma confinement and heating in magnetically confined fusion plasmas; intense laser–plasma interactions in inertially confined fusion plasmas, and x-ray lasers; ionospheric, solar system, and astrophysical plasmas; coherent electromagnetic generation and amplification with intense electron beams; and low-temperature plasma applications.

Inertial confinement and laser–plasma interaction papers describe detailed studies on filamentation and other nonlinear dynamics in long-scale-length plasmas. New domains of nonlinear plasma physics, which are becoming accessible with short-pulse ultra-high-intensity lasers, are also reviewed. (The review paper by E. M. Campbell arrived too late to appear in this issue; it will be published in a forthcoming, regular issue.) Spectroscopy in inertial confinement plasmas and in soft x-ray laser research is reviewed by H. Griem, this year's winner of the American Physical Society's James Clerk Maxwell Prize.

2315 Phys. Fluids B 4 (7), July 1992

Development and applications of compact high-intensity lasers*

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(Received 18 December 1991; accepted 12 March 1992)

The development of compact high-intensity lasers, made possible by the technique of chirped pulse amplification, is reviewed. This includes the complexities of high-power laser implementation, such as the generation of short pulses, pulse cleaning, wide-bandwidth amplification, temporal stretching and compression, and the requirements for high-average powers. Details of specific solid-state laser systems are given. Some applications of these lasers to short-pulse coherent short-wavelength [x-ray ultraviolet (XUV)] sources are also reviewed. This includes several nonlinear effects observed by focusing a subpicosecond laser into a gas; namely, an anomalous scaling of harmonic generation in atomic media, an upper limit on the conversion efficiency of relativistic harmonics in a plasma, and the observation of short-pulse self-focusing and multifoci formation. Finally, the effects of large ponderomotive pressures (100 Mbars) in short-pulse high-intensity laser–plasma interactions are discussed, with relevance both to recombination x-ray lasers and a novel method of igniting thermonuclear fusion.

I. INTRODUCTION

It is now possible with the technique of chirped pulse amplification to build compact solid-state lasers that produce ultrashort pulses with intensities three to four orders of magnitude higher than was previously possible. These pulses have multiterawatt peak power, and when focused can produce intensities in the range of 10^{18} W/cm^2. The electric field at the laser focus at this intensity is approximately 3×10^{10} V/cm. Since this greatly exceeds the Coulomb electric field seen by the valence electrons, it results in both collisionless ionization without tunneling, and highly nonlinear interactions with bound electrons. For 1 μm light, the field is high enough, in fact, to cause plasma electrons to oscillate at relativistic velocities, and thus exhibit highly nonlinear motion due to the magnetic component of the Lorentz force. For the first time, this allows the study of nonlinear optics involving free electrons. These

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pulses also have extremely short time durations, in the range of 100 fsec to 1 psec. Since this is shorter than the timescales of either significant hydrodynamic motion or thermal equilibration, short-scale length, solid-density, and nonequilibrium plasmas may be produced. Furthermore, the high-average powers of these lasers make possible the use of sampling techniques to study inherently statistical phenomena. Applications of these novel laser interactions include the generation of coherent x-ray ultraviolet (XUV) radiation, the ignition of laser-fusion targets, and the acceleration of electrons. In this paper, we will present the state-of-the-art for ultraintense laser pulse generation using chirped pulse amplification, and discuss some of their current and potential applications in the field of—what has become known as—high-field science. Most of the work

II. HIGH-INTENSITY LASER DEVELOPMENT

It is a tribute to scientific and engineering ingenuity that—due to a series of breakthroughs—the laser has, since its inception, produced ever higher power pulses.

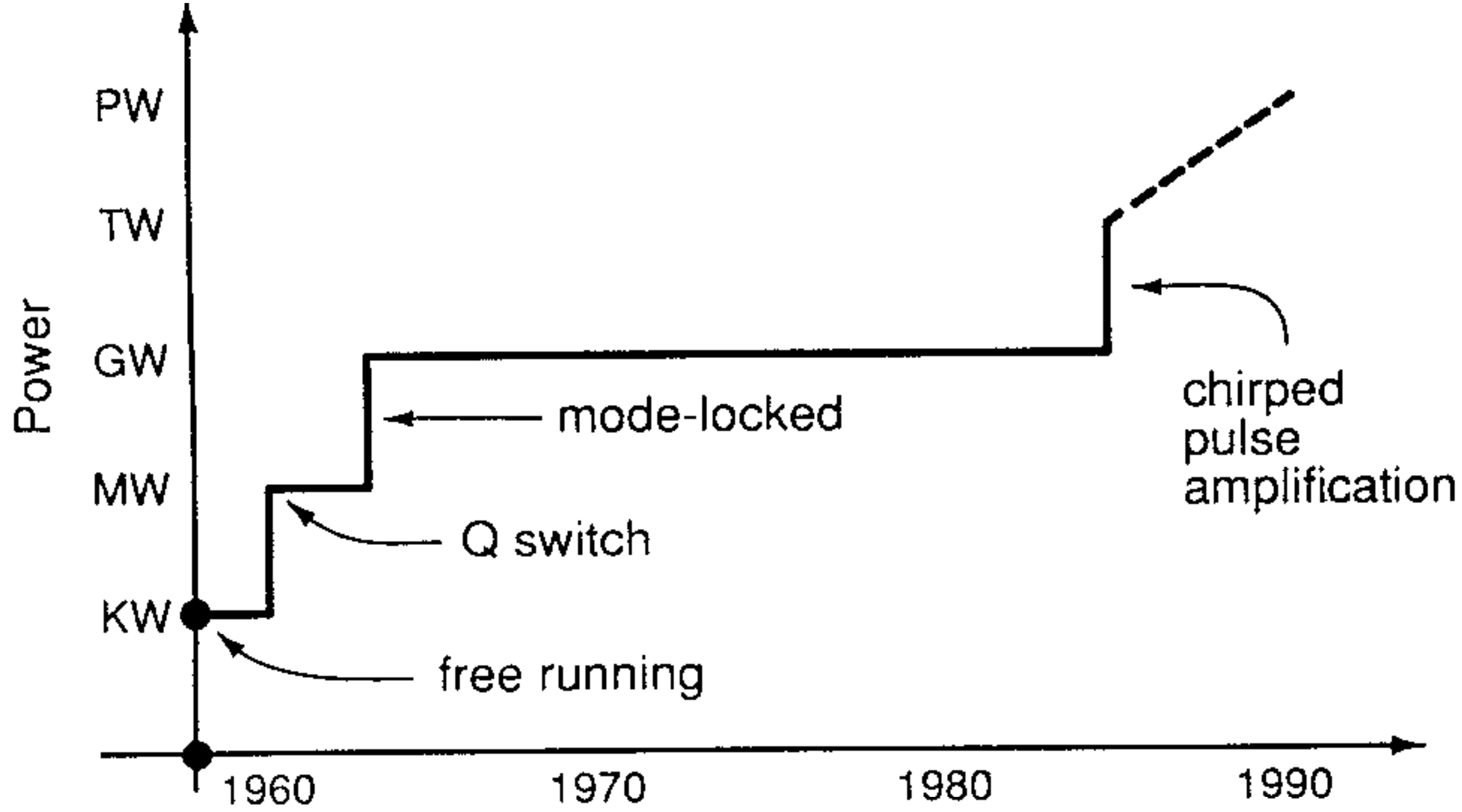


FIG. 1. Peak-power capability of small aperture $[O(\mathrm{cm}^2)]$ laser amplifiers has increased stepwise through the years.

A. Chirped pulse amplification

The amplification of short optical pulses to high-energy levels requires the fulfillment of three conditions. First, the bandwidth of the gain medium should be broad enough to accommodate the laser pulse spectrum. Second, the amplifying medium should have superior energy storage. Third, the laser intensity should be kept low enough to avoid nonlinear wave-front distortion.

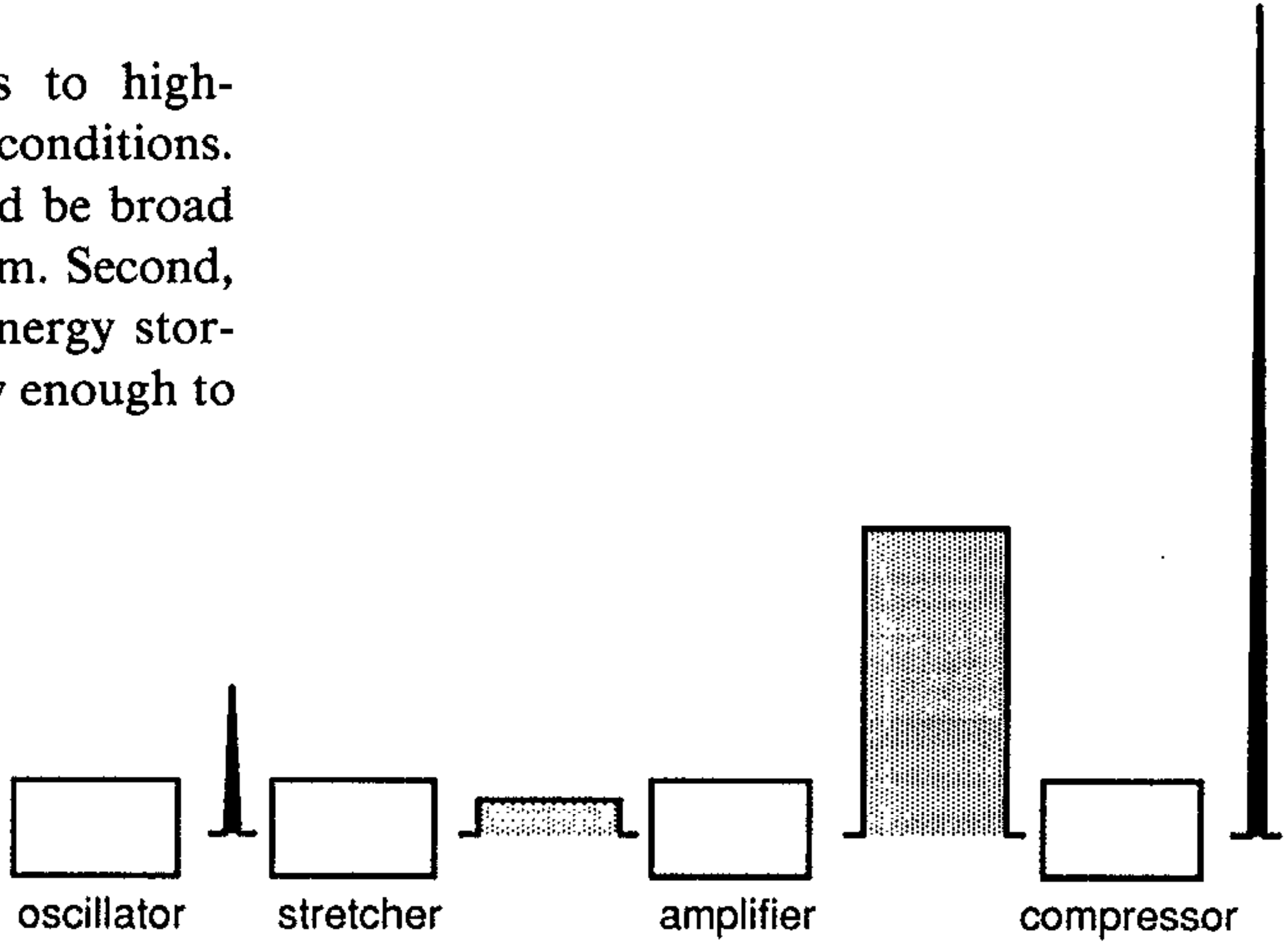
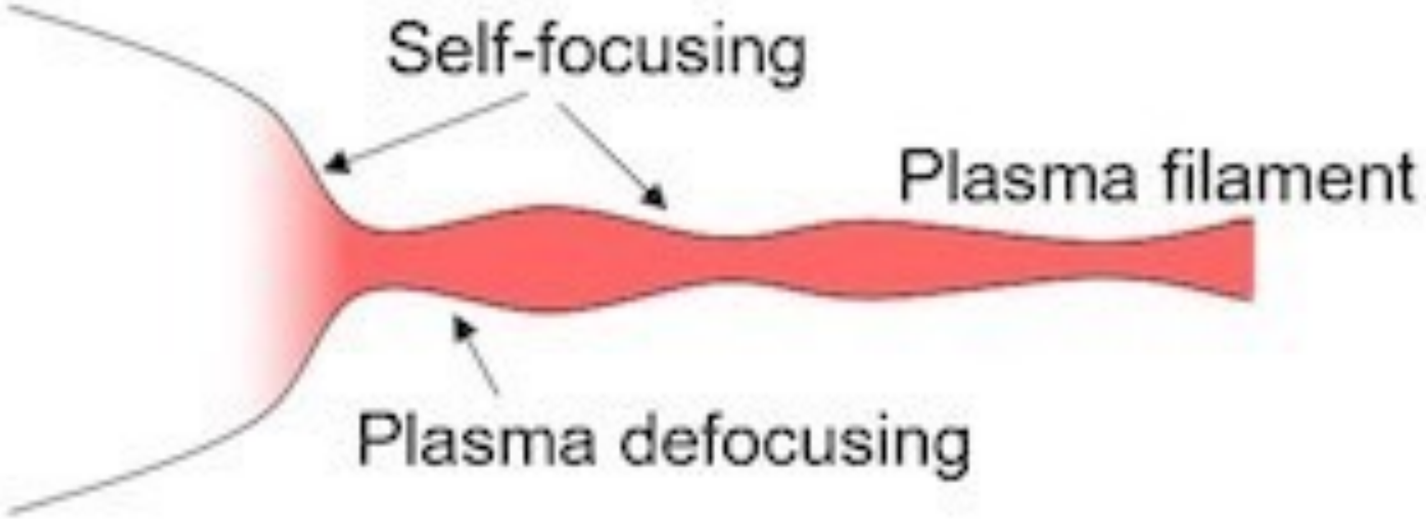


FIG. 2. In chirped pulse amplification, the pulse is temporally stretched in order to the lower peak intensity before amplification. After the stored energy is extracted from the amplifier, the pulse is temporally compressed to the initial duration. This allows the use of high-energy-storage materials for short-pulse amplification.

D. Competition between ponderomotive and thermal pressures

The ponderomotive pressure $(n_e m\langle v_{os}^2\rangle)$ of the laser is enormous. Assuming the intensity and wavelength used in the experiment $(v_0/c \sim 0.05)$ and critical density, it exceeds a Mbar. At higher intensity, it may reach the same order of magnitude as the thermal pressure associated with a fusion target. For this reason, this mechanism has also generated interest as a novel means of igniting thermonuclear fusion. Long-pulse lasers could heat and compress the fuel pellet through the usual ablation of the target. By the further heating and compression of the fuel with its enormous light pressure, an intense short-pulse laser may then be used as the ignitor.[34]



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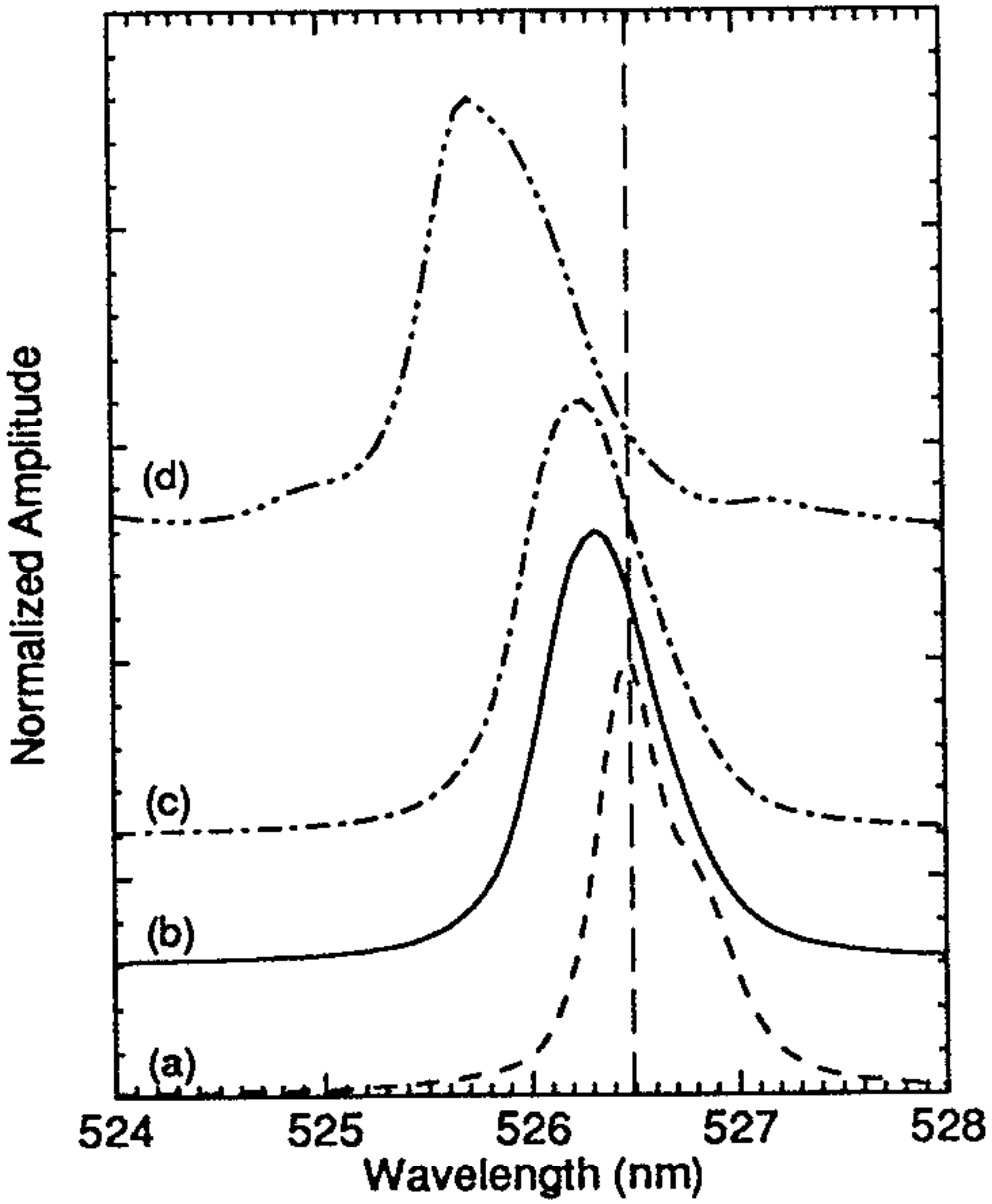

FIG. 7. The dynamics of the plasma is dominated by light pressure when the oscillatory energy of electrons in the field of the laser exceeds their thermal energy. (a) Spectrum of the light incident on the target. Doppler-shifted spectrum of the light reflected from the moving critical surface: (b) measured experimentally; (c) calculated numerically with the ponderomotive force included; (d) calculated numerically without the ponderomotive force.

Superposition, Entanglement, and Raising Schrödinger’s Cat

Nobel Lecture, December 8, 2012

by David J. Wineland

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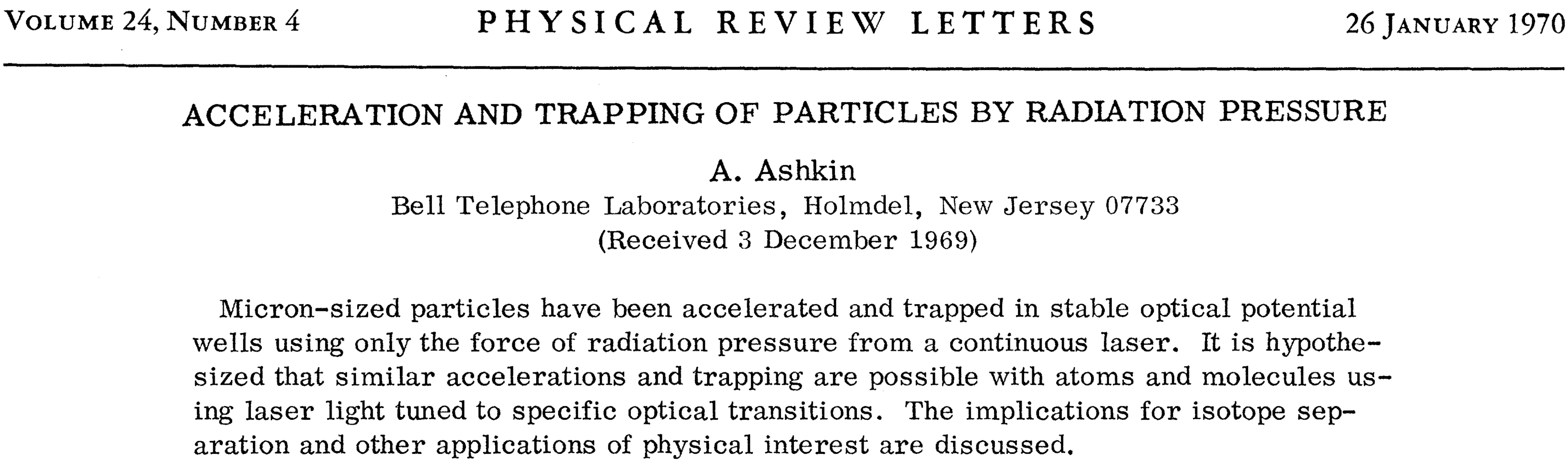
The modes of motion for a single charged particle in a Penning trap include one circular mode about the trap axis called the magnetron mode. For the electron g-factor experiments, it was desirable to locate the electron as close to the trap axis as possible by reducing the amplitude of this mode. This could be accomplished with a form of “sideband cooling” (Wineland and Dehmelt 1975a, 1976) as demonstrated in (Van Dyck *et al.* 1978). Around this time, I was also stimulated by the papers of Arthur Ashkin (Ashkin 1970a, b) on the possibilities of radiation pressure from lasers affecting the motion of atoms. In analogy with the electron sideband cooling, Dehmelt and I came up with a scheme for cooling trapped-ion motion with laser beams (Wineland and Dehmelt 1975b, see below). The cooling could also be explained in terms of velocity-dependent radiation pressure as in a concurrent proposal by Ted Hänsch and Art Schawlow (Hänsch and Schawlow 1975). We didn’t anticipate all of the uses of laser cooling at the time, but it was clear that it would be important for high-resolution spectroscopy of trapped ions. For example, the largest systematic uncertainty in the



VOLUME 24, NUMBER 4 PHYSICAL REVIEW LETTERS 26 JANUARY 1970

ACCELERATION AND TRAPPING OF PARTICLES BY RADIATION PRESSURE

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(Received 3 December 1969)

Micron-sized particles have been accelerated and trapped in stable optical potential wells using only the force of radiation pressure from a continuous laser. It is hypothesized that similar accelerations and trapping are possible with atoms and molecules using laser light tuned to specific optical transitions. The implications for isotope separation and other applications of physical interest are discussed.

This Letter reports the first observation of acceleration of freely suspended particles by the forces of radiation pressure from cw visible laser light.

specific resonances. The author's interest in radiation pressure from lasers stems from a realization of the large magnitude of the force, and the observation that it could be utilized in a way which avoids disturbing thermal effects. For instance a power $P=1$ W of cw argon laser light at $\lambda=0.5145$ μm focused on a lossless dielectric sphere of radius $r=\lambda$ and density $=1$ gm/cc gives a radiation pressure force $F_{\mathrm{rad}}=2qP/c=6.6\times10^{-5}$ dyn, where q, the fraction of light effectively reflected back, is assumed to be of order 0.1. The acceleration $=1.2\times10^{8}$ cm/sec$^2\cong10^5$ times the acceleration of gravity.

The first experiment used transparent latex spheres[6] of 0.59-, 1.31-, and 2.68-μm diam freely suspended in water. A TEM$_{00}$-mode beam of an argon laser of radius $w_0 = 6.2$ μm and $\lambda = 0.5145$ μm was focused horizontally through a glass cell 120 μm thick and manipulated to focus on single particles. See Fig. 1(a). Results were observed with a microscope.

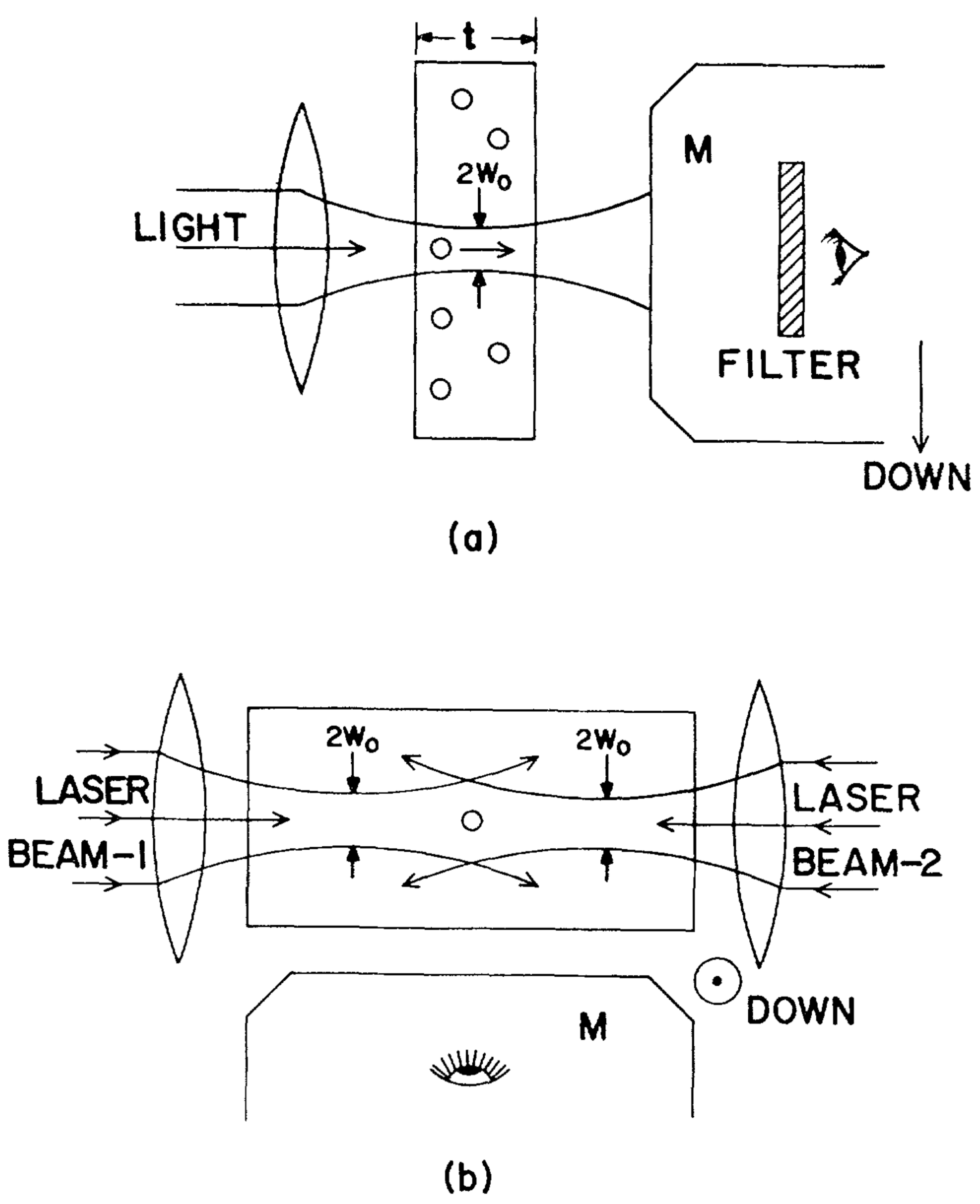


FIG. 1. (a) Geometry of glass cell, $t = 120$ μm, for observing micron particle motions in a focused laser beam with a microscope M. (b) The trapping of a high-index particle in a stable optical well. Note position of the TEM$_{00}$-mode beam waists.

on single particles. See Fig. 1(a). Results were observed with a microscope. If a beam with milliwatts of power hits a 2.68-μm sphere off center, the sphere is simultaneously drawn in to the beam axis and accelerated in the direction of the light. It moves with a limiting velocity of microns per second until it hits the front surface of the glass cell where it remains trapped in the beam. If the beam is blocked, the sphere wanders off by Brownian motion. Similar effects occur with the other sphere sizes but more power is required for comparable velocities. When mixed, one can accelerate 2.68-μm spheres and leave 0.585-μm spheres behind.

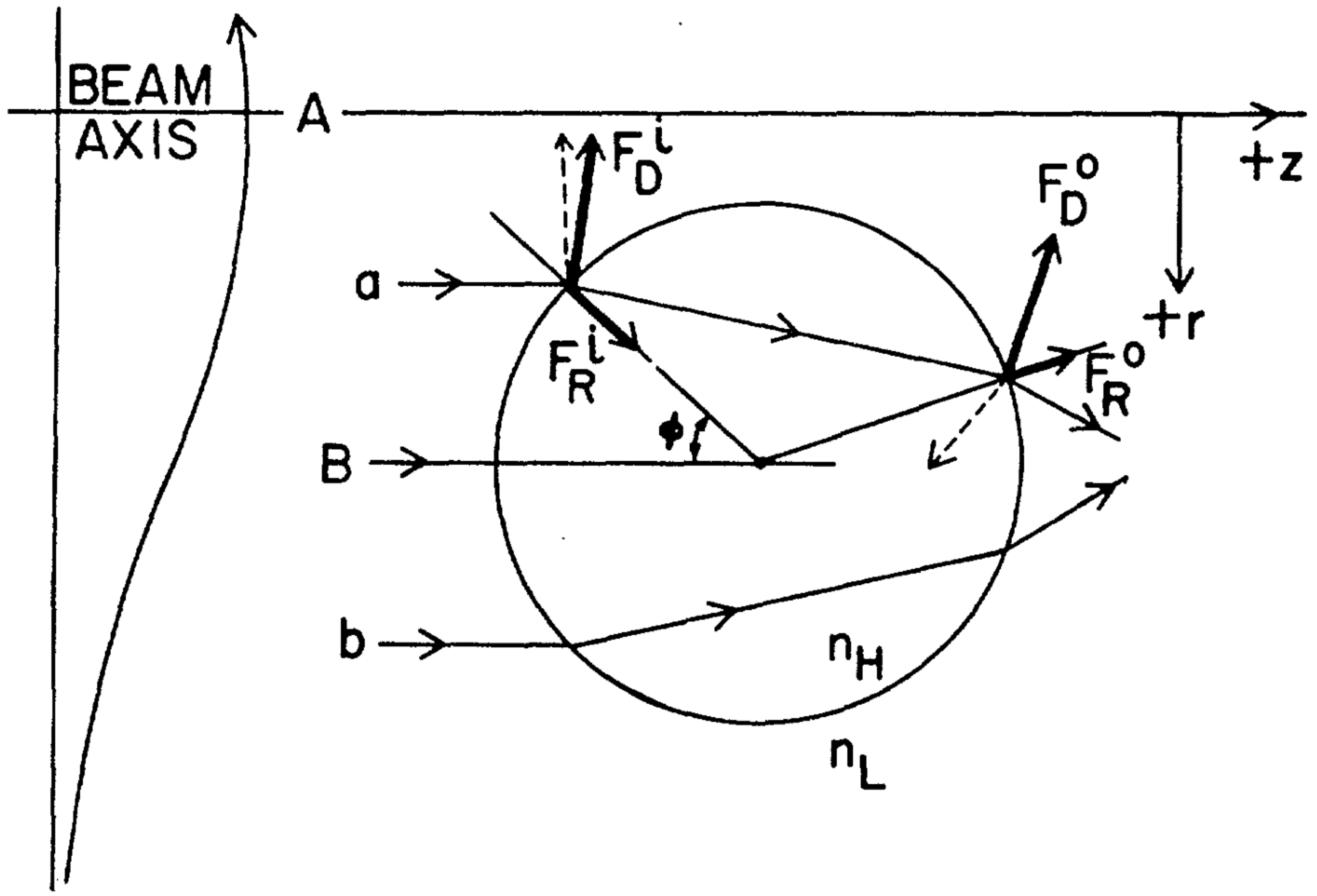


FIG. 2. A dielectric sphere situated off the axis A of a TEM_{00}-mode beam and a pair of symmetric rays a and b. The forces due to a are shown for $n_H > n_L$. The sphere moves toward $+z$ and $-r$.

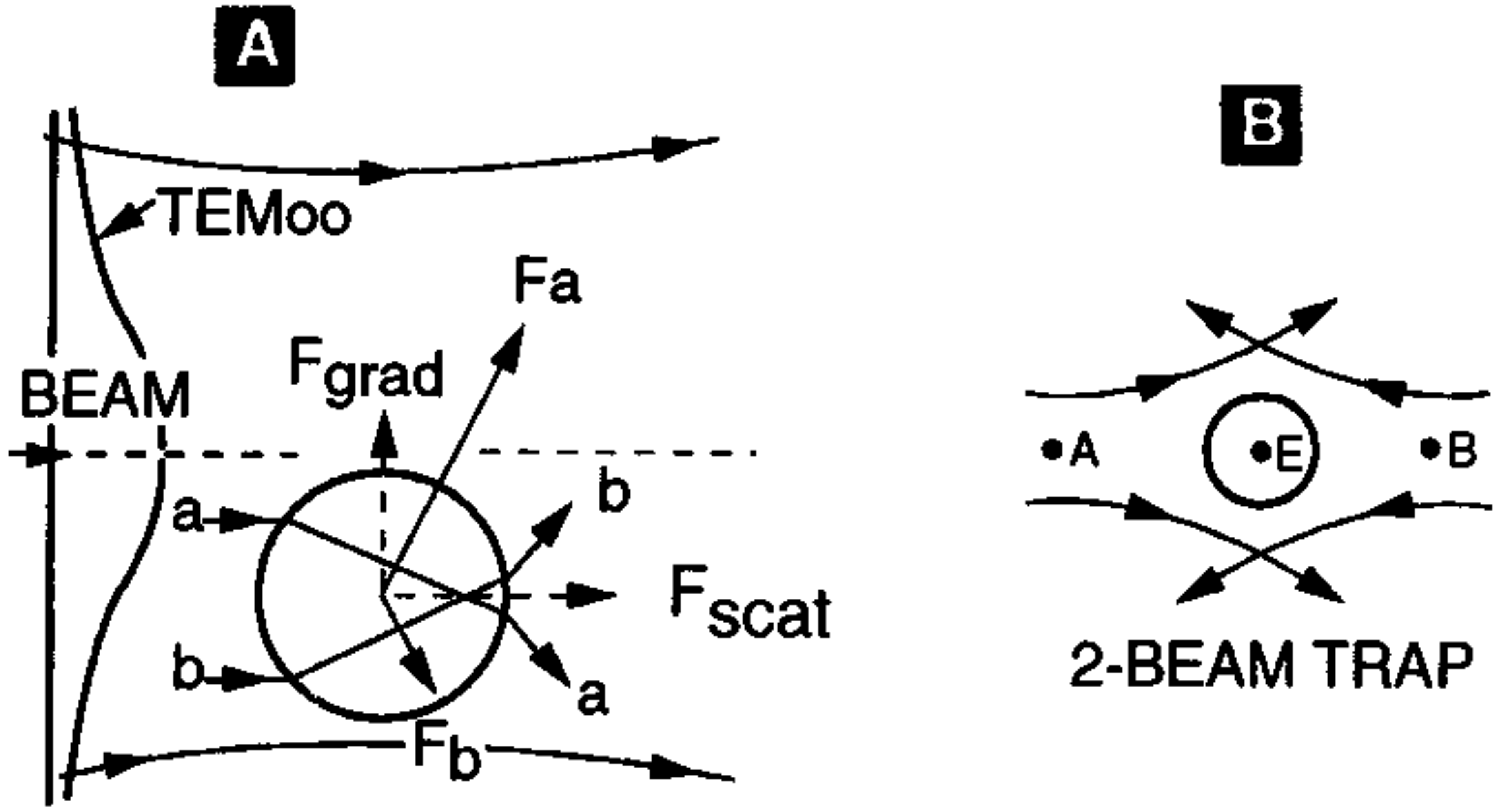


FIG. 1. (*A*) Origin of F_{scat} and F_{grad} for high index sphere displaced from TEM_{00} beam axis. (*B*) Geometry of 2-beam trap.

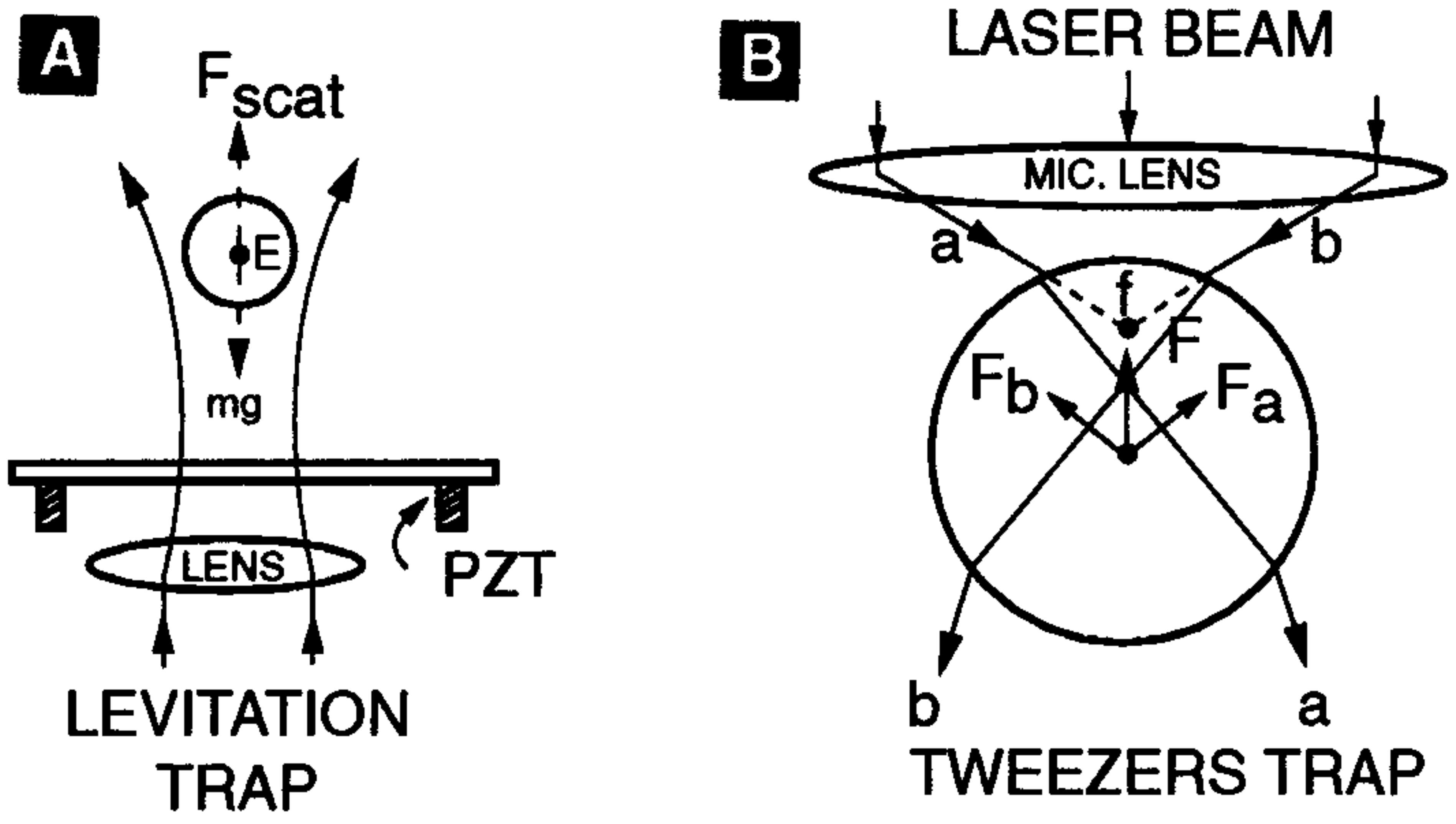
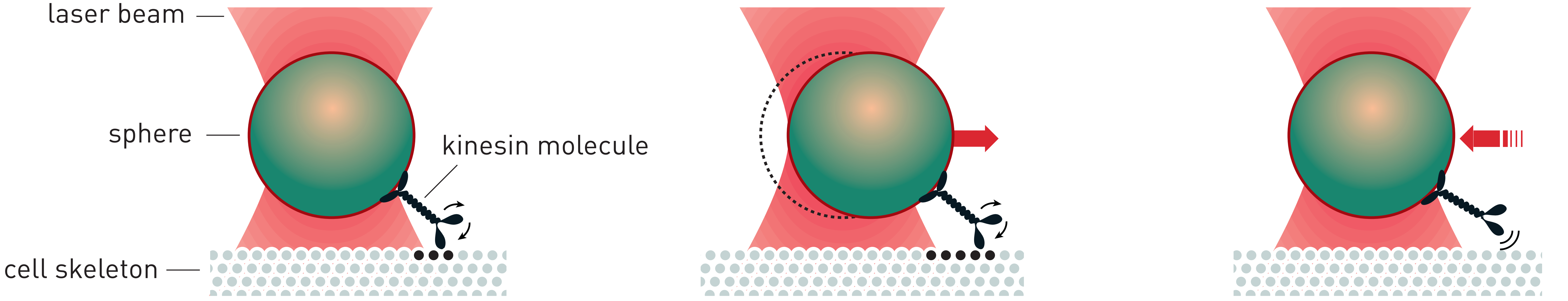


FIG. 2. (*A*) Geometry of levitation trap. (*B*) Origin of backward restoring force F for sphere located below tweezers focus *f*.

Ashkin opened up a whole world of new applications with his optical tweezers. One important breakthrough was the ability to investigate the mechanical properties of molecular motors, large molecules that perform vital work inside cells. The first one to be mapped in detail using optical tweezers was a motor protein, kinesin, and its stepwise movement along microtubules, which are part of the cell's skeleton.

A motor molecule walks inside the light trap



1 The kinesin molecule attaches to a small sphere held by the optical tweezers.

2 Kinesin marches away along the cell skeleton. It pulls the sphere, making it possible to measure the kinesin's stepwise motion.

3 Finally, the motor molecule can no longer withstand the force of the light trap and the sphere is forced back to the centre of the beam.

Figure 2. The optical tweezers map the molecular motor kinesin as it walks along the cell skeleton.

Julio M. Fernandez

https://biology.columbia.edu/people/fernandez

Graduate Student Solves Quantum Verification Problem

Urmila Mahadev spent eight years in graduate school solving one of the most basic questions in quantum computation: How do you know whether a quantum computer has done anything quantum at all?

But once a quantum computer can perform computations a classical computer can't, how will we know if it has done them correctly? If you distrust an ordinary computer, you can, in theory, scrutinize every step of its computations for yourself. But quantum systems are fundamentally resistant to this kind of checking. For one thing, their inner workings are incredibly complex: Writing down a description of the internal state of a computer with just a few hundred quantum bits (or "qubits") would require a hard drive larger than the entire visible universe.

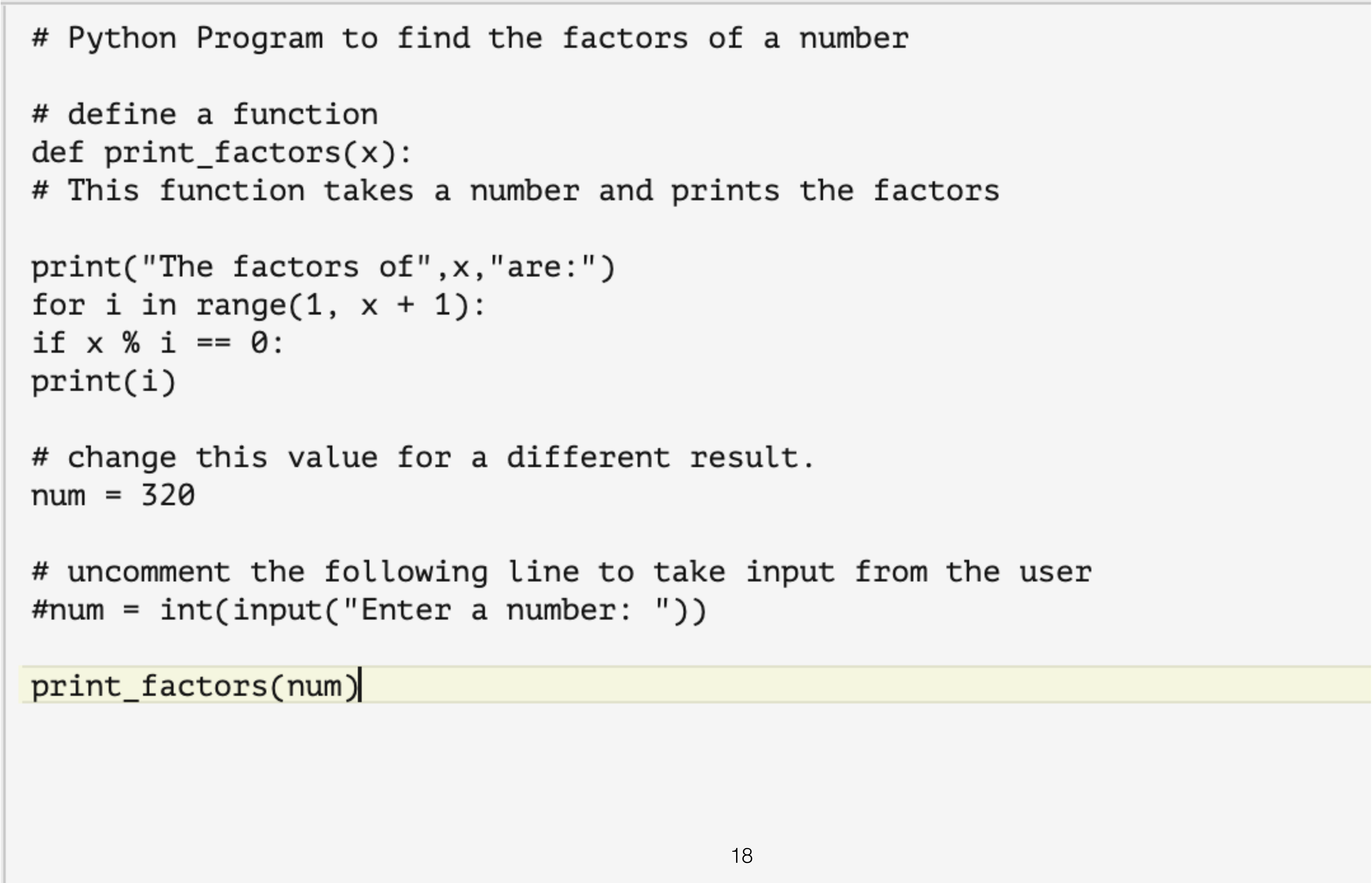
https://www.quantamagazine.org/graduate-student-solves-quantum-verification-problem-20181008/

D-Wave offers the first public access to a quantum computer

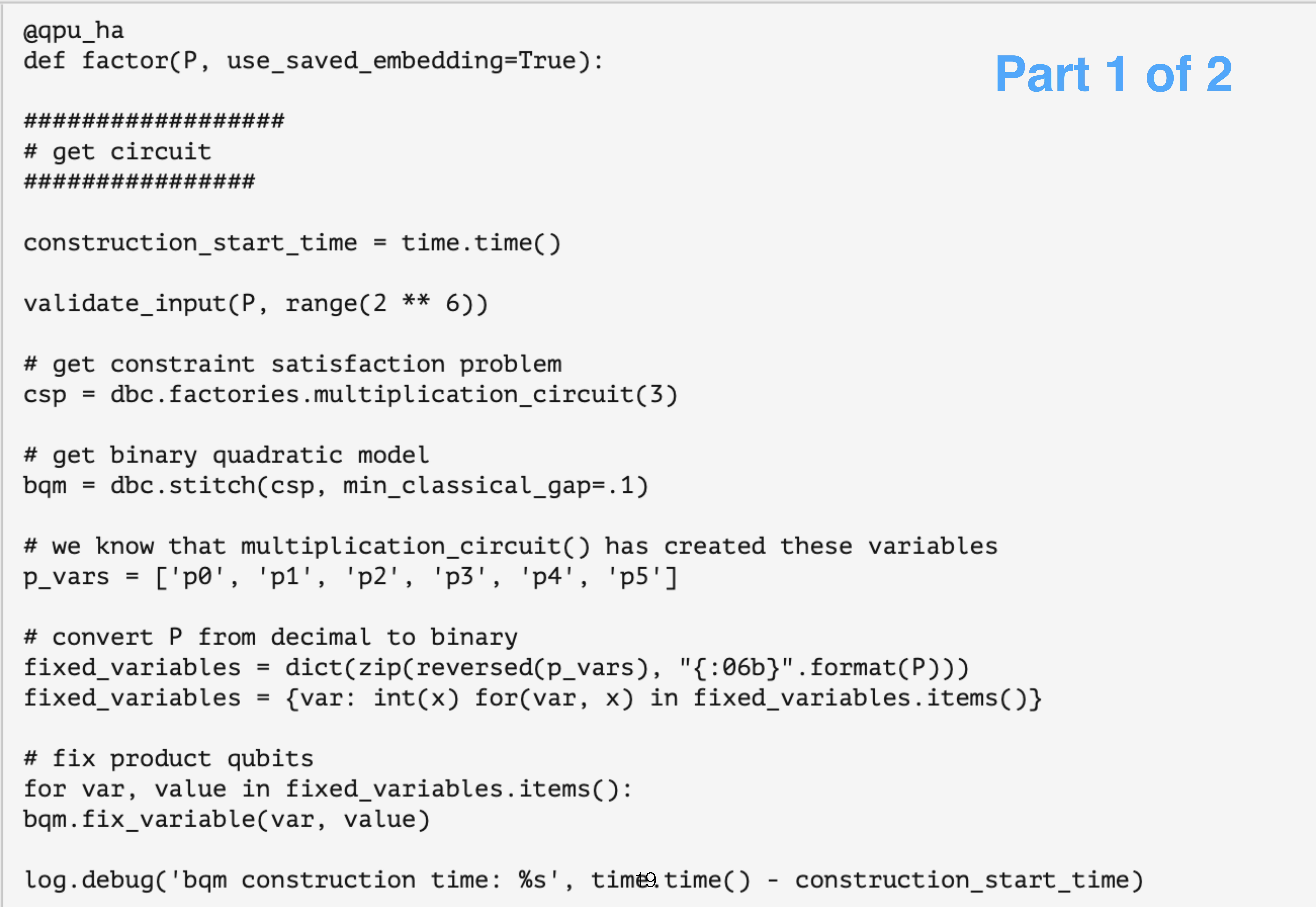
From Python to parallel universes

https://techcrunch.com/2018/10/05/d-wave-offers-the-first-public-access-to-a-quantum-computer/

To get started on the road to quantum computing, D-Wave built the Leap platform. The Leap is an open-source toolkit for developers. When you sign up you receive one minute's worth of quantum processing unit time which, given that most problems run in milliseconds, is more than enough to begin experimenting. A queue manager lines up your code and runs it in the order received and the answers are spit out almost instantly.



```
# Python Program to find the factors of a number

# define a function
def print_factors(x):
# This function takes a number and prints the factors

print("The factors of",x,"are:")
for i in range(1, x + 1):
if x % i == 0:
print(i)

# change this value for a different result.
num = 320

# uncomment the following line to take input from the user
#num = int(input("Enter a number: "))

print_factors(num)
```



Part 1 of 2

```
@qpu_ha
def factor(P, use_saved_embedding=True):

##################
# get circuit
################

construction_start_time = time.time()

validate_input(P, range(2 ** 6))

# get constraint satisfaction problem
csp = dbc.factories.multiplication_circuit(3)

# get binary quadratic model
bqm = dbc.stitch(csp, min_classical_gap=.1)

# we know that multiplication_circuit() has created these variables
p_vars = ['p0', 'p1', 'p2', 'p3', 'p4', 'p5']

# convert P from decimal to binary
fixed_variables = dict(zip(reversed(p_vars), "{:06b}".format(P)))
fixed_variables = {var: int(x) for(var, x) in fixed_variables.items()}

# fix product qubits
for var, value in fixed_variables.items():
bqm.fix_variable(var, value)

log.debug('bqm construction time: %s', time.time() - construction_start_time)
```

Part 2 of 2

```
#############
# run problem
#############

sample_time = time.time()

# get QPU sampler
sampler = DWaveSampler(solver_features=dict(online=True, name='DW_2000Q.*'))
_, target_edgelist, target_adjacency = sampler.structure

if use_saved_embedding:
# load a pre-calculated embedding
from factoring.embedding import embeddings
embedding = embeddings[sampler.solver.id]
else:
# get the embedding
embedding = minorminer.find_embedding(bqm.quadratic, target_edgelist)
if bqm and not embedding:
raise ValueError("no embedding found")

# apply the embedding to the given problem to map it to the sampler
bqm_embedded = dimod.embed_bqm(bqm, embedding, target_adjacency, 3.0)

# draw samples from the QPU
kwargs = {}
if 'num_reads' in sampler.parameters:
kwargs['num_reads'] = 50
if 'answer_mode' in sampler.parameters:
kwargs['answer_mode'] = 'histogram'
response = sampler.sample(bqm_embedded, **kwargs)

# convert back to the original problem space
response = dimod.unembed_response(response, embedding, source_bqm=bqm)

sampler.client.close()

log.debug('embedding and sampling time: %s', time.time() - sample_time)
```

Next Week:

Let’s try to write a q-compute program…