

CHAPTER 9

ENERGY

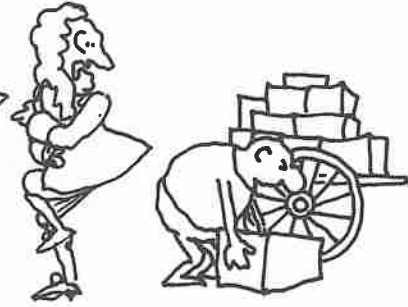
ISAAC NEWTON ALMOST
SINGLE-HANDEDLY INVENTED
THE SCIENCE OF MECHANICS,
BUT THERE IS ONE CONCEPT
HE MISSED: **ENERGY**.



ENERGY COMES IN MANY FORMS, BUT THE BASIC DEFINITION IS IN TERMS OF

WORK.

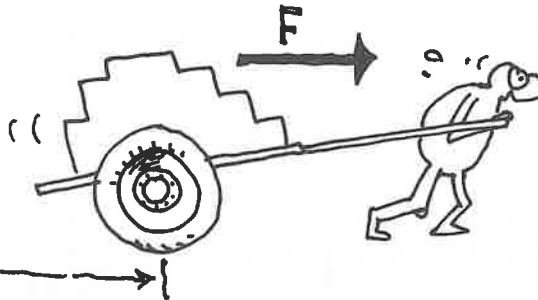
NO WONDER I AVOIDED THE LOATHSOME IDEA!



WE ALL HAVE A CONCEPT OF WORK, BUT IN PHYSICS, THE DEFINITION IS VERY PRECISE: WE SAY THAT WORK IS DONE WHEN A FORCE F MOVES A BODY THROUGH A DISTANCE d . WORK IS DEFINED AS FORCE TIMES DISTANCE.

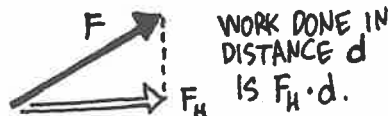
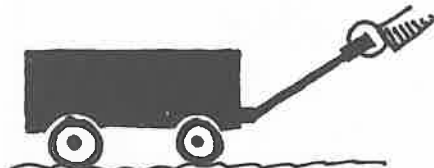


IT'S ALMOST TOO PAINFUL TO WATCH.



$$W = F \times d$$

IN THIS DEFINITION, ONLY THE FORCE IN THE DIRECTION OF MOTION COUNTS. IF I PULL A WAGON AT AN ANGLE, ONLY THE HORIZONTAL PART OF THE PULL DOES ANY WORK.

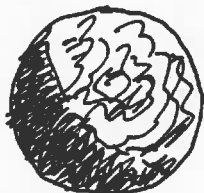
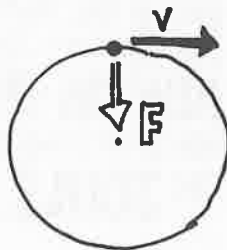
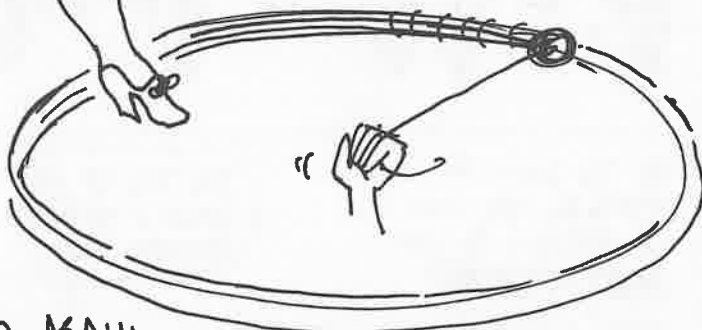


FORCE



WHEN A WAITRESS CARRIES A TRAY AROUND, HER SUPPORT FORCE DOES NO WORK, BECAUSE IT IS PERPENDICULAR TO THE MOTION.

IF I WHIRL A BALL ON A STRING AT CONSTANT SPEED, AGAIN NO WORK IS DONE. THE INWARD FORCE IS ALWAYS PERPENDICULAR TO THE (TANGENTIAL) VELOCITY OF THE BALL. (BUT I DO HAVE TO DO SOME WORK TO SET IT WHIRLING IN THE FIRST PLACE.)



SO MUCH ACTION, SO LITTLE WORK!



THIS SHOWS, INCIDENTALLY, THAT, INsofar AS THE MOON'S ORBIT IS CIRCULAR, THE EARTH DOES NO WORK ON THE MOON!! THE GRAVITATIONAL FORCE IS PERPENDICULAR TO THE MOTION.

ENERGY

IS DEFINED AS THE CAPACITY TO DO WORK. THE RELEASE OF ENERGY DOES WORK — AND DOING WORK ON SOMETHING ADDS ENERGY TO IT. SO — ENERGY AND WORK ARE ACTUALLY **EQUIVALENT CONCEPTS**, AND WE WRITE :

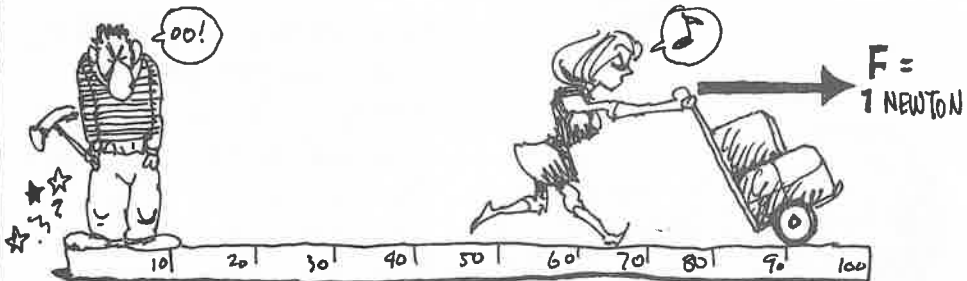
$$E = W = F \times d.$$

IN THE ENGLISH SYSTEM, THE UNIT OF ENERGY IS THE **FOOT-POUND** (FEET \times POUNDS), AND IN THE METRIC SYSTEM IT'S THE **NEWTON-METER**, WHICH IS ALSO CALLED THE **JOULE**.

YOU TELL 'EM ABOUT THE JOULE — I'M GOING TO TRY POUNDING FEET...



SO: ONE **JOULE** = THE ABILITY TO EXERT A FORCE OF ONE **NEWTON** OVER A DISTANCE OF ONE **METER**.



KINETIC & POTENTIAL ENERGY



SUPPOSE I THROW A BALL. I DO WORK GETTING THE BALL MOVING: I EXERT A FORCE F OVER A DISTANCE d . THE BALL THEN HAS ACQUIRED SOME ENERGY, THE ENERGY OF MOTION, OR **KINETIC** ENERGY. A SIMPLE MATHEMATICAL DERIVATION* SHOWS THAT

$$K.E. = \frac{1}{2}mv^2$$

HERE m IS THE BALL'S MASS, AND v IS ITS VELOCITY.

ON THE OTHER HAND, SUPPOSE I LIFT RINGO TO A HEIGHT h . AS I EXERT A FORCE $W =$ RINGO'S WEIGHT OVER A DISTANCE h , I DO WORK $W \cdot h = mgh$. RINGO ISN'T MOVING AT THE END, BUT HE STILL HAS AN ADDED ENERGY OF mgh , JUST BECAUSE OF WHERE HE IS IN THE EARTH'S GRAVITATIONAL FIELD. THIS ENERGY IS CALLED HIS **POTENTIAL** ENERGY.

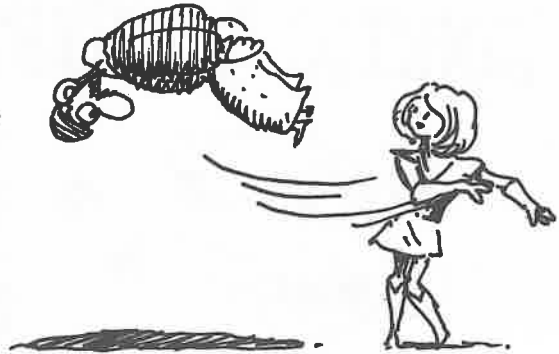
$$P.E. = mgh.$$



* ASSUME F CONSTANT. $F = ma$, SO $KE = F \cdot d = mad$. BUT $d = \frac{1}{2}at^2$, SO $KE = \frac{1}{2}m(at)^2$. BUT $v = at$, SO $KE = \frac{1}{2}mv^2$.

POTENTIAL ENERGY IS POTENTIAL BECAUSE IT CAN BE GOTTEN BACK AS "REAL" KINETIC ENERGY. ALL I HAVE TO DO IS LET RINGO FALL!

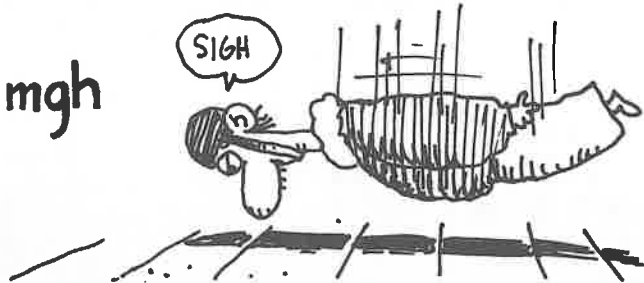
OH, COME ON!



AS HE FALLS FASTER AND FASTER, HIS POTENTIAL ENERGY IS GRADUALLY CONVERTED INTO KINETIC ENERGY. AT THE BOTTOM, JUST BEFORE IMPACT, HIS POTENTIAL ENERGY IS ZERO, AND HIS ORIGINAL POTENTIAL ENERGY HAS BECOME ENTIRELY KINETIC. THAT IS,

$$\frac{1}{2}mv^2 = mgh$$

SIGH



FROM THIS YOU CAN SOLVE FOR v , HIS VELOCITY UPON IMPACT. $v = \sqrt{2gh}$.

DO YOU THINK LUCY HAS A SADISTIC STREAK?



THIS LAST EQUALITY $\frac{1}{2}mv^2 = mgh$ IS AN EXAMPLE OF

★ CONSERVATION OF ENERGY. ★

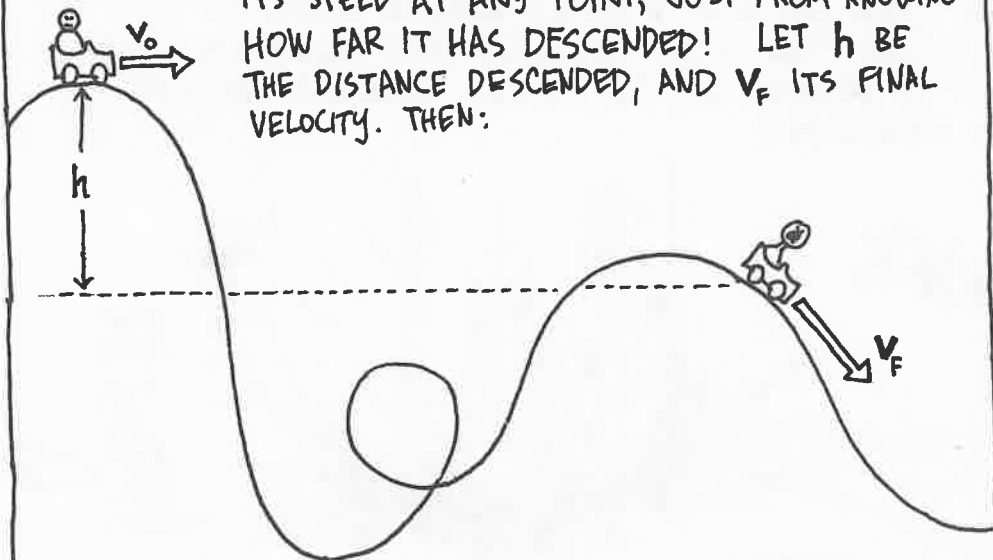


AS THE CONCEPT OF ENERGY WAS DEVELOPED, PHYSICISTS GRADUALLY REALIZED THAT ENERGY, LIKE MOMENTUM, IS CONSERVED.



(THE CONFUSING PART WAS THAT ENERGY, UNLIKE MOMENTUM, APPEARS IN MANY DISGUISES, SUCH AS HEAT, AS WE'LL SEE.)

HERE'S AN APPLICATION OF ENERGY CONSERVATION. IF v_0 IS THE INITIAL SPEED OF THIS ROLLER COASTER, WE CAN COMPUTE ITS SPEED AT ANY POINT, JUST FROM KNOWING HOW FAR IT HAS DESCENDED! LET h BE THE DISTANCE DESCENDED, AND v_f ITS FINAL VELOCITY. THEN:



INITIAL ENERGY = $\frac{1}{2}mv_0^2 + mgh$

FINAL ENERGY = $\frac{1}{2}mv_f^2$

THESE ARE EQUAL, BY CONSERVATION OF ENERGY.

$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_0^2 + mgh$, so

$v_f = \sqrt{v_0^2 + 2gh}$

CONSERVATION OF ENERGY TELLS US THAT THE TOTAL ENERGY OF THE SYSTEM DOES NOT CHANGE — BUT THE ENERGY MAY BE CONVERTED INTO OTHER FORMS. WHAT HAPPENS TO RINGO'S ENERGY WHEN HE HITS THE FLOOR? NOW BOTH THE KINETIC AND POTENTIAL ENERGIES ARE GONE!



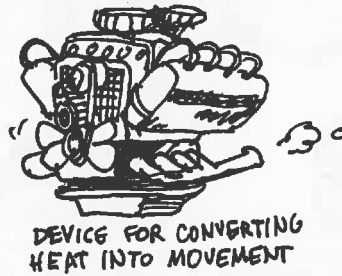
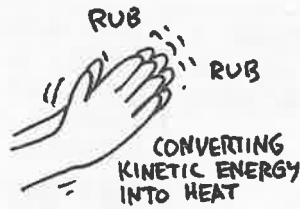
WHERE DID THEY GO?

LET'S LOOK AT THE IMPACT ITSELF. SOME OF THE ENERGY IS CONVERTED INTO **SOUND**. SOME GOES INTO DISTORTING THE FLOOR — AND DISTORTING RINGO, FOR THAT MATTER. AND SOME, EVEN MOST, GOES INTO **HEAT**. RINGO AND THE FLOOR ARE BOTH A LITTLE WARMER AFTER THE COLLISION. THE IMPACT JIGGLES THEIR MOLECULES — AND HEAT IS NOTHING BUT THE KINETIC ENERGY OF BILLIONS OF MOLECULES !!!

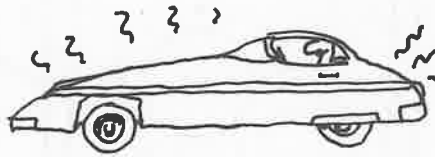


VARIOUS FORMS OF ENERGY CHANGE INTO EACH OTHER CONSTANTLY. IN THE SCIENCE OF **THERMODYNAMICS**

WE LEARN THAT IT IS EASY TO CONVERT KINETIC ENERGY INTO HEAT, BUT MUCH HARDER TO CONVERT HEAT INTO KINETIC ENERGY.



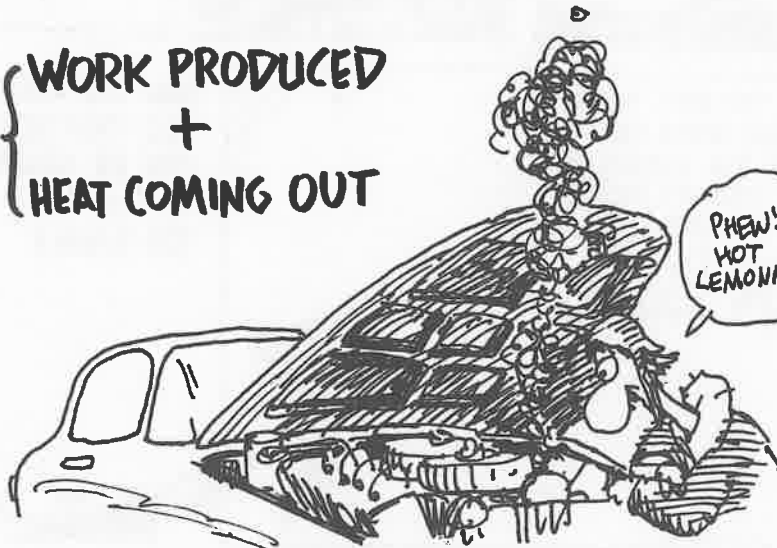
CAR ENGINES CONVERT HEAT INTO MOVEMENT, BUT NOT EFFICIENTLY. YOUR CAR NEEDS A COOLING SYSTEM, AND MUCH HEAT ESCAPES.



RESULT: HEAT POLLUTION!

BUT ENERGY IS ALWAYS CONSERVED - IN OTHER WORDS:

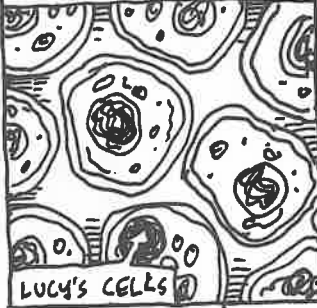
$$\text{HEAT GOING IN} = \left\{ \begin{array}{l} \text{WORK PRODUCED} \\ + \\ \text{HEAT COMING OUT} \end{array} \right.$$



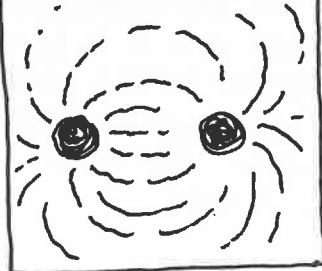
WHEN I LIFT RINGO, I PUT ENERGY INTO HIM. WHERE DID THAT ENERGY COME FROM?



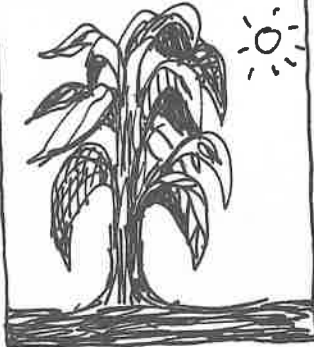
IT'S MUSCULAR ENERGY, WHICH IN TURN IS RELEASED CHEMICAL ENERGY CAUSED BY FOOD OXIDIZING IN MY BODY.



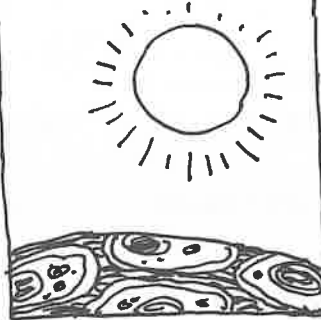
CHEMICAL ENERGY IS A FORM OF POTENTIAL ENERGY, OWING TO THE POSITIONS OF ELECTRONS IN MOLECULES' ELECTRICAL FIELDS.



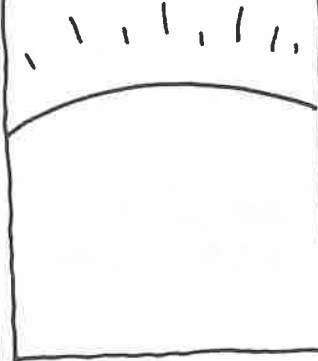
THE CHEMICAL ENERGY CAME FROM A PLANT THAT I ATE. (I'M A VEGETARIAN.)



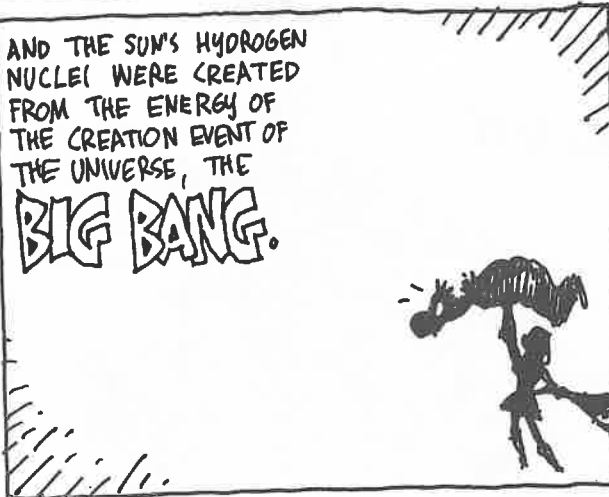
THE PLANT CONVERTED THE RADIANT ENERGY OF SUNLIGHT INTO CHEMICAL ENERGY VIA PHOTOSYNTHESIS.



THE SUNLIGHT CAME FROM NUCLEAR FUSION IN THE SUN.



AND THE SUN'S HYDROGEN NUCLEI WERE CREATED FROM THE ENERGY OF THE CREATION EVENT OF THE UNIVERSE, THE **BIG BANG.**



EVEN THE ENERGY MOVING THE CARTOONIST'S PEN CAN BE TRACED BACK IN THIS WAY TO THE BIG BANG !!