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NOMENCLATURE

A	area of titanium piece
CB	conduction band
C_{SC}	semiconductor-electrolyte capacity
D	donor atom of an n-type semiconductor
E_C	energy level of the conduction band
E_D	energy level of the semiconductor decomposition
E_F	Fermi energy level
Efb	flat band energy level
Eg	energy band gap
g(x)	carrier generation
ΔG	free energy of the chemical reaction
h	hole carriers of a semiconductor
ΔH	enthalpy energy of the chemical reaction
I	current density
I_{sc}	short-circuit current density
I_o	exchange current density
I_a	intensity of the sunlight
Iav	average intensity of the sunlight
J	photocurrent density
l	distance of spot light and the anode electrode
l_b	depletion region width
L_p	hole diffusion length
n	electron carrier of a semiconductor
N_D	donor concentration of an n-type semiconductor

Ns	flux of photons
p	hole concentration
q	magnitude of electronic charge
r	rate of hydrogen evolution
T	absolute temperature
V_b	voltage of a bias
Vfb	flat band potential
Voc	oper circuit voltage of solar cell
VB	valence band
w_1	weight of a titanium piece
w_2	weight of a titanium dioxide piece
x	thickness of the titanium dioxide film
α	absorption coefficient
η	conversion efficiency
ε	dielectric constant of the semiconductor
ε_o	permittivity of free space
$\phi(x)$	photon flux at distance x
σ^S	solution space charge density
ρ_{Ti}	titanium density
ρ_{TiO_2}	titanium dioxide density
λ	wavelength of light
Φ	work function

APPENDIX A

APPENDIX A

A.1 The pn Junction

A pn junction is not the interface between two pieces of semiconductor of opposite type pressed together. It is a single piece of crystal lattice which contains an excess of donor impurities on one side and of acceptor impurities on the other. The making junction are alloying, diffusion, epitaxy and ion implantation.(40,4)

Considering the physical picture of the junctions in Figure A.1.1., shows before and after contacting of semiconductor characteristices and pn junction, too. The electrons, which are abundant on the n-side,diffuse into the p-side, where there are very few of them. Hole diffusion in the opposite direction (in Figure A.1.1b), this phenomena causes the current flows by diffusion of electrons and holes, called as the diffusion currents. This flows cause an immediate loss of neutrality : the n-side, losing electrons, is charged positive because of the net donor charge left behide, the p-side similarly becomes negatively charged. A potential barrier (V_B) builds up across the junction which blocks any further majority carrier diffusion and makes the current zero, as it would be in equilibrium (Figure A.1.1c). One can consider that the electric potential difference that forms causes drift currents which exactly balance the diffusion currents set up by the concentration gradients.

From Figure A.1.1d, a region nust therefore exist, on both sides of the metallurgical junction, in which there is a built-in field in equilibrium and in which there are few, if any, mobile carriers, since the field sweeps then away. This region is called the depletion layer.

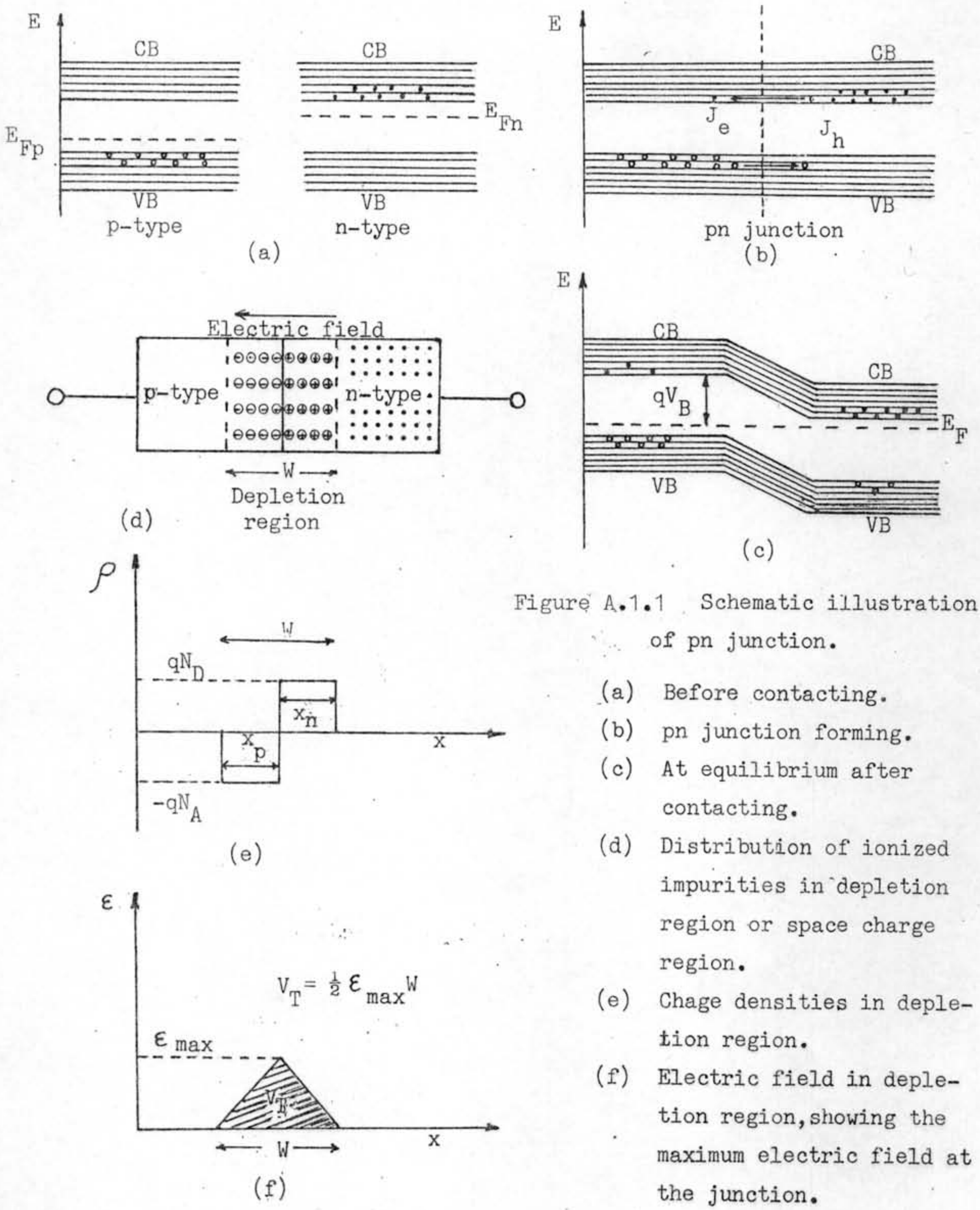


Figure A.1.1 Schematic illustration of pn junction.

(a) Before contacting.
(b) pn junction forming.
(c) At equilibrium after contacting.
(d) Distribution of ionized impurities in depletion region or space charge region.
(e) Chage densities in depletion region.
(f) Electric field in depletion region, showing the maximum electric field at the junction.

Note

J_e = electron flow
J_h = hole flow
W = depletion layer

⊖ = ionized acceptors
⊕ = ionized donors
V_B = built-in voltage

It is a space-charge region because of the net ionized impurities charge in it.

At equilibrium for n-side, hole concentration equals ni^2/N_D and N_A is the hole concentration of p-side, the build-in voltage denoted by V_B (40) :

$$V_B = \frac{kT}{q} \ln (N_A N_D/n_i^2) \qquad \text{...A.1.1}$$

and the maximum field, ε_{max}, occurs at the metallurgical junction is

$$\varepsilon_{max} = q N_D x_n / \varepsilon\varepsilon_o \qquad \text{...A.1.2}$$

where x_n is electron diffusion length and ε is dielectric constant. From Figure A.1.1f, V_T, the tolal electrostatic potential variation from on side of the junction to the other, is

$$V_T = \tfrac{1}{2} \varepsilon_{max} W$$

where W is depletion region width,

$$W = x_n + x_p$$

thus $$W = (2\varepsilon\varepsilon_o (N_A + N_D) / q N_A N_D)^{\frac{1}{2}} V_T^{\frac{1}{2}} \qquad \text{...A.1.3}$$

For $N_D >> N_A$ doping of n-and p-types in the junction, the W is modified from A.1.3,

$$W = (2\varepsilon\varepsilon_o / q N_A)^{\frac{1}{2}} . V_T^{\frac{1}{2}} \qquad \text{...A.1.4}$$

and the capacitance of the junction is defined as follow$^{(40)}$

$$C_{SC} = \varepsilon\varepsilon_o / W \qquad \text{...A.1.5}$$

where C_{SC} is a capacitance of the junction and ε is dielectric constanct of a semiconductor. By substituting W of Eq. A.1.4 to Eq. 4.1.5, this C_{SC} equation is

$$C_{SC} = \varepsilon\varepsilon_o / (2\varepsilon\varepsilon_o V_T / qN_A)^{\frac{1}{2}}$$

or $$1/C_{SC}^2 = 2V_T / q \varepsilon\varepsilon_o N_A \qquad \text{...A.1.6}$$

The p-n junction form is known as, a semiconductor diode. For the I-V curve charactistic of diode, studied from the junction under forward bias and reverse bias (Figure A.1.2)

A forward bias condition is established by applying the positive potential to the p-type side and the negative potential to the n-type side, as shown in Figure A.1.2a. The minority-carrier flow has not changed in magnitude but the magnitude of the majority carrier flow will increase exponentially will increasing forward bias. Thus, net current, I now flows in the circuit because of diffusion of majority carriers, in the wide diode, I is given by

$$I = I_h + I_e = I_o (\exp qV_A/kT - 1) \qquad \ldots A.1.7$$

where I_h, I_e and I_o are the hole flow current, electron flow current and satuated current, respectively. If two ohmic contacts are attached to the opposite sides of the p and n regions and an external positive voltage V_A applied, the total potential barrier at the junction is reduced to

$$V_T = V_B - V_A \qquad \ldots A.1.8$$

Thus, the width of the depletion region of forward bias is smaller than no bias by Eq.A.1.6 and Eq.A.1.8.

For the reverse bias (Figure A.1,2b), the positive terminal is connected to the n-type side and the negative terminal to the p-type side. In this case, the widening of the depletion region will establish too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero. And the net current is

$$I = I_o\left[(\exp - qV_A/kT) - 1)\right] \qquad \ldots A.1.9$$

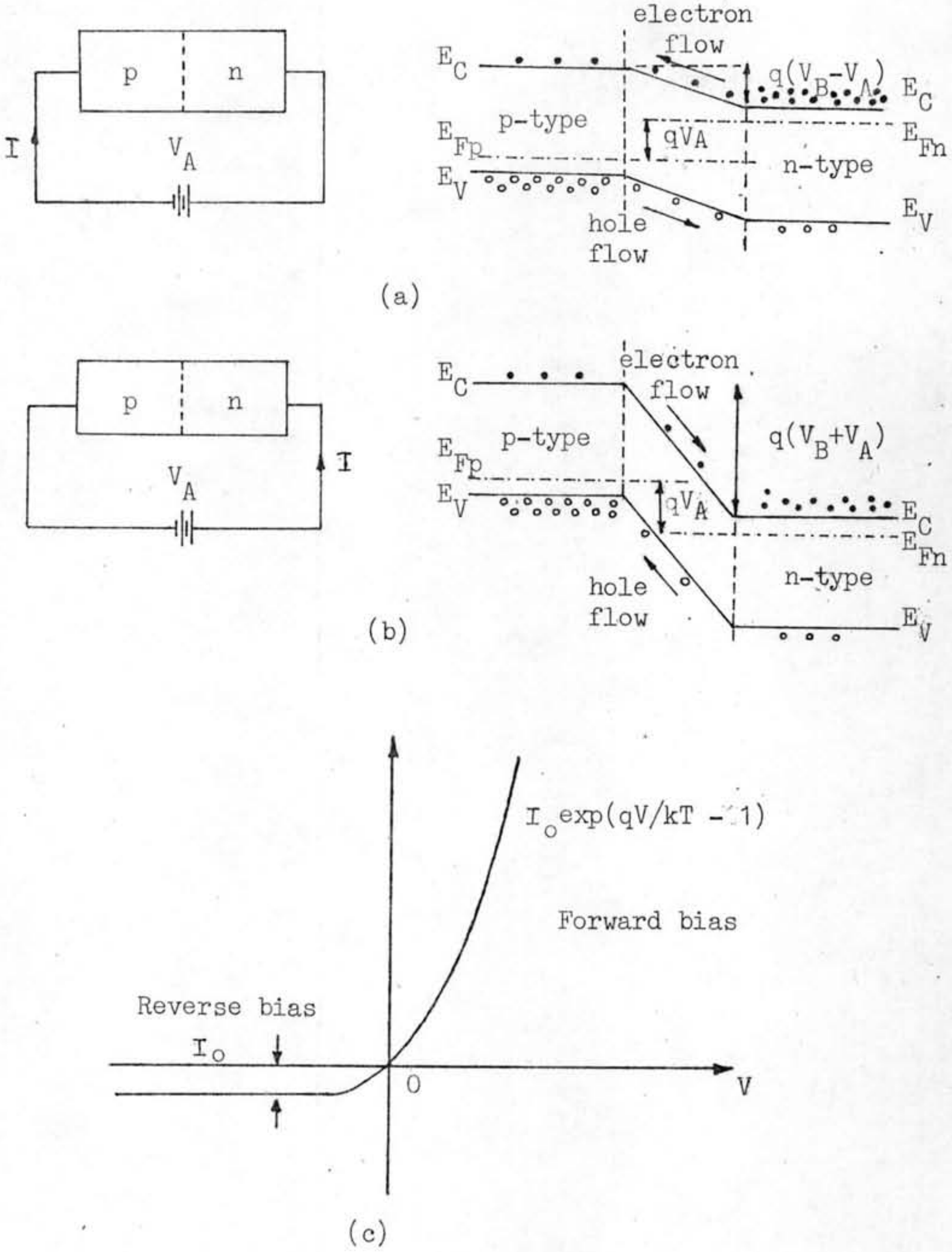


Figure A.1.2 The biased diode characteristics

(a) Forward biased pn junction

(b) Reverse biased pn junction

(c) The I-V curve of biased diode

at 300 K, $\exp(-q V_{A/kT}) << 1$, thus $I \simeq I_o$
The current that exists under this condition is called the satuation current and both the I -V characteristic of forward and reverse : bias is showing in Fig. A.1.2c.

A.2 Solar Cells

Diodes mode for direct conversion of solar energy to electricity are so-called solar cells, they are p-n junction diodes or Sohotlky diodes (metal-semiconductor junction, see 4.2.1).

For a p-n junction diode, when sunlight is allowed to fall on the junction, as also shown in Figure. A.2.1

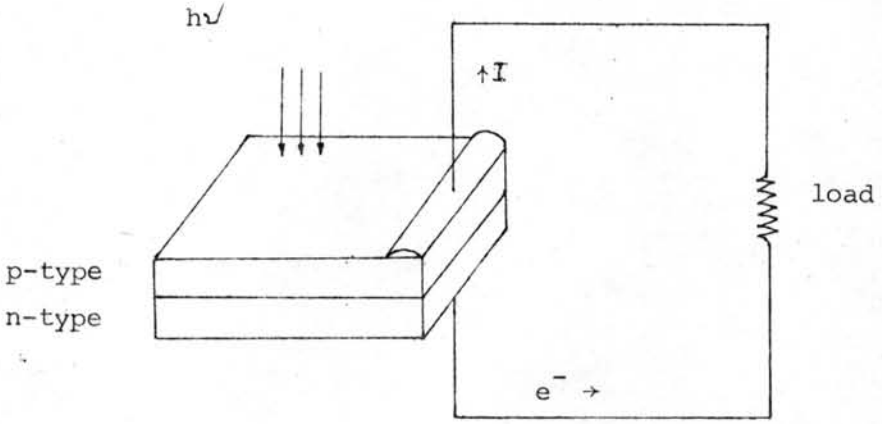


Figure A.2.1 The direct electronic conversion of solar energy to electricity.

By photobiased the solar all, the electrical generation can supply to the external load, and the equivalent circuit is respresented in Figure A.2.2. From Fig.A.2.2, the applied load current is ;

$$I = I_s - I_j$$

and

$$I_j = I_o (\exp qV/\eta kT - 1)$$

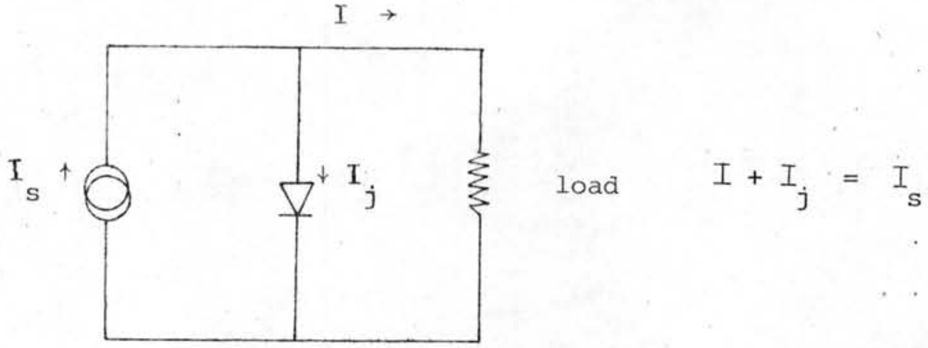


Figure A.2.2. Simple equivalent circuit of solar cell

where I_o is reverse saturation current, η is a junction perfection factor (for Si, $1 < \eta < 2$) and I_s is current through the junction.

According to solar cell is a p-n junction, the I-V characteristic (Figure A.2.3) is like its forward biased diode (A.1.2c)

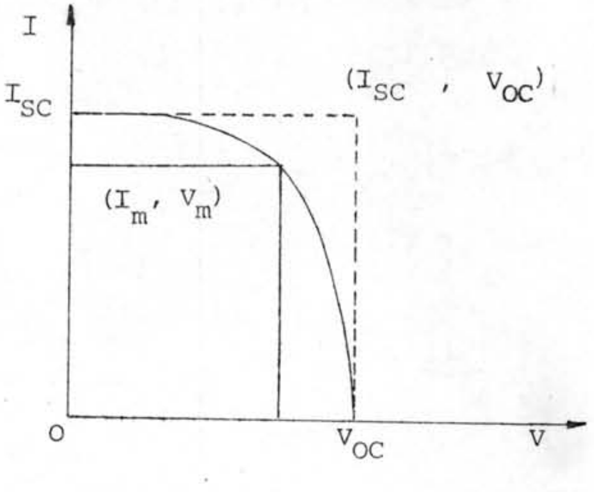


Figure A.2.3 The I-V characteristics of a solar cell.

In an ideal photovoltaic cell, the I.V product is insensitive to load and equals the product of the short circuit current, $_{SC}$, times the open circuit voltages V_{OC}. Practical power (I-V product) from I-V curve gives a maximum power point, as shown in Figure A.2.3. The ratio $I_mV_m/I_{SC}V_{OC}$ is known as the fill factor. And the efficiency is the percent of the sunlight power converted to electrical power ($I_m \cdot V_m$) by Eq.3.5.2a;($I_m . V_m$/ sunlight power) x 100%

A.3 Electrochemical Cells

Considering the processes and factors affecting the transport of charge across interfaces between chemical phase, one of the two phases is an electrolyte, which is merely a phase through which charge is carried by the movement of ions. Electrolyte may be liquid solutions or fused salts. The second phase at the boundary might be another electrolyte, or it might be an electrode, which is a phase through which charges is carried by electronics movement. Electrodes can be metals or semiconductors. For electrochemical cells, these systems are defined most generally as two electrodes seperated by at least one electrolyte phase.

Two types of processes occur at electrodes. One considering the structure of the electrode-solution interface is analogous to that of a capacitor. At a given potential their will exist a charge on the metal electrode, q^m, and a charge in the solution, q^s (Figure A.3.1). Whether the charge on the metal is negative or positive with respect to the solution depends on the potential across the interface and the composition of the solution. Under this condition a given electrode-solut-

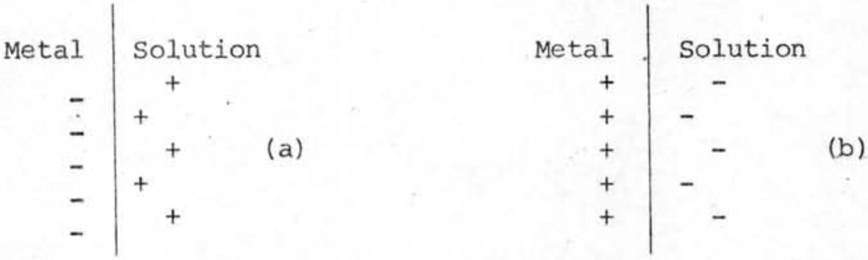
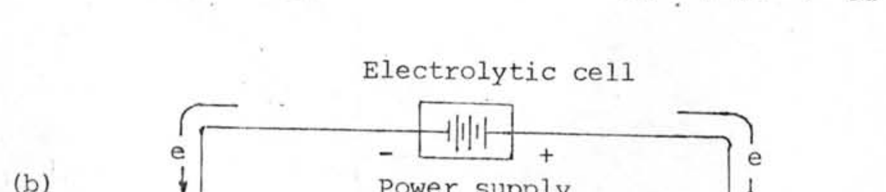


Figure A.3.1 The metal-solution interface as a capacitor with a charge on the metal, q^m(a) negative and (b) positive.

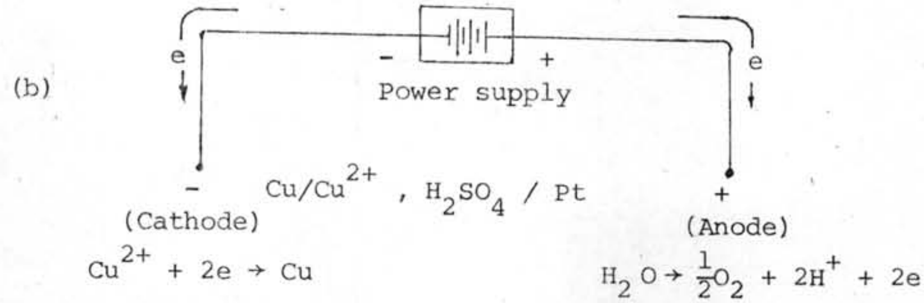
ion interface will show a range of potentials where no charge transfer reactions occur because such reactions are thermodynamically or kinetically unfavorable. These processes are called nonfaradaic processes. The other, charges (e.g. electrons) are transfered across the metalsolution interface and this process causes oxidation or reduction to occur. Since these reactions are governed by Faraday's law (i.e., the amount of chemical reaction caused by the flow of current is proportional to the amount of the amount of electricity passed) they are called faradaic process, classified as either galvanic or electrolytic cells. A galvanic cell is one in which reactions occur spontaneousely at the electrodes when they are connected externally by a conductor (Figure A.3.2a). These cells are often employed in converting chemical energy into electrical energy. An electrolytic cell is one in which reactions are effected by the imposition of an external voltage greater than the reversible potential of the cell (Figure A.3.2b). These cells are frequently employed to carry out desired chemical reactions by explanding electrical energy.

Figure A.3.2

Galvanic cell



Electrolytic cell



In general, there is a measurable difference in potential between the two electrodes whether the cell is passing or not. The magnitude of the potential difference at an interface affects the relative energies of the carrier in the phases; hence it controls the direction of charge transfer. The overall chemical reaction taking place in a cell is made up of two independent half-reactions, which decribe the real chemical changes at two electrodes. Each the half-reaction responds to the potential difference measured with respect to the reference, called as electrode potential or half-reaction potential. The values are showed in Table A.3, with respect to NHE (Normal Hydrogen Electrode) at standard condition $25^{\circ}c$. The potentials are measured with respect to reference electrode NHE, which is convenitent from an experimental standpoint, so the most common reference is the saturated calomel electrode (SCE), which is 0.24 V vs. NHE (see Figure 4.4.1)

On the other hand, the prediction of overall chemical reaction is considering the free energy (ΔG°), which is functional of the cell reaction potential or emf (E°_{rxn});

$$\Delta G^{\circ} = -nFE^{\circ}_{rxn} \qquad \ldots A.3.1$$

where n is the number of electrons passed per atom of reactant component reacted, and F is the charge on a mole of electrons, which is about 96,500C. This implies a positive emf when reaction is spontaneous, which $E^{\circ}_{rxn} = E^{\circ}_{(red)} - E^{\circ}_{(ox)}$; $E^{\circ}_{(red)}$ and $E^{\circ}_{(ox)}$ are the half-reaction potentials of the reduction reaction (at cathode) and the oxidation reaction (at anode) respectively. For example in Figure A.3.2a, for galvanic cell, $E^{\circ}_{Cu^{2+}/Cu}=0.34$ V and $E^{\circ}_{Zn^{2+}/Zn} = -.0.76$ V, from Table A.3. The overall reaction is therefore $E^{o}_{(red)} = E^{o}_{Cu^{2+}/Cu}$ and $E^{o}_{Zn^{2+}/Cu}$, then the E^{o}_{rxn} is + 1.10V,

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$$

it is the spontaneous reaction, converting chemical energy to electrical energy with 1.10 V emf. And Figure A.3.2b, for the overall reaction;

$$Cu^{2+} + H_2O \rightarrow Cu + \frac{1}{2}O_2 + 2H^{+}$$

where $E^{o}_{(red)} = E^{o}_{Cu^{2+}/Cu}$ and $E^{o}_{(ox)} = E^{o}_{O2/H_2O}$, then the E^{o}_{rxn} is - 0.88 V, it is nonspontaneous reaction, but this reaction is occured by external power supply with the minimum voltage of 0.88 V.

In electrolytic cells, amount of chemical reaction caused by the current is proportional to the amount of electricity passed by Faraday's law of electrolysis. Michael Faraday (1832) found one mole electron (6.02×10^{23} electrons) for a reaction when amount of electricity of 96,500C or 1 F (Faraday) passed. For example according to 1 F from power supply of the cell (Figure A.3.2b), a half mole of cupper is generated (two electrons is used for one atom of cupper).

The amount of electricity, Q is I X t, where I electrical current (amp) and t time of electrolysis (sec). Thus the energy supply for electrolytic cell is E X Q, where E is voltage (which the minimum value of E depents on E^{o} of a reaction in cell)

The E^{o} is defined for the standard potential of the reaction but in experiments, E is not at standard condition. For the general reaction:

$$aA + bB \rightarrow eE + fF$$

E is defined by Walter Nernst (1889);(8)

$$E = E^{o} \frac{2.303RT}{nF} \log \frac{[E]^{e} [F]^{f}}{[A]^{a} [B]^{b}} \qquad ...A.3.2$$

where [A],[B] = concentration of reactants A and B

[E],[F] = concentration of products E and F

Half reactions in Table A.3 are reduction ~~forms~~. Their potentials are the reaction potential of cells, consisting of an Standard Hydrogen Electrode (SHE) and another electrode, whose potentials are to be measured.(8) The standard potentials are the values which measured at 25°c and concentration of ions are unity or pressure of gases are 1 atm.

Table A.3 Standard reduction potentials at 25°c(5)

Reduction	Potential, E^o (V)
$Ag^+ + e \rightleftarrows Ag$	0.80
$Au^+ + e \rightleftarrows Au$	1.68
$Cu^{2+} + 2e \rightleftarrows Cu$	0.34
$Fe^{3+} + e \rightleftarrows Fe^{2+}$ (1 M HCl)	0.77
$2H^+ + 2e \rightleftarrows H_2$	0.00
$2H_2O + 2e \rightleftarrows H_2 + OH^-$	-0.83
$H_2O_2 + 2H^+ + 2e \rightleftarrows 2H_2O$	1.78
$O_2 + 2H^+ + 2e \rightleftarrows H_2O_2$	0.68
$O_2 + 4H^+ + 4e \rightleftarrows 2H_2O$	1.23
$O_2 + 2H_2O + 4e \rightleftarrows 4OH^-$	0.40
$Pt^{2+} + 2e \rightleftarrows Pt$	~1.2
$Ti^{2+} + 2e^- \rightleftarrows Ti$	-1.75(9)

APPENDIX B

APPENDIX B

B.1 Calculation of TiO_2 thickness

	ρ, densities(gm/cc)	M.W.
Titanium metal, Ti	4.43	47.90
Titanium dioxide, TiO_2	4.06	79.90

Given x_o = titanium dioxide thickness, cm

y = the consumed thickness of a Ti-piece after thermal oxidation, cm

A = area of the Ti-sheet, cm^2

Thermal oxidation:

$$\begin{array}{lll} Ti + O_2 & TiO_2 & .....B.1.1 \\ 47.90\ gm \quad 32\ gm & 79.90\ gm & \\ yA\rho & x_o A\rho_{TiO_2} & \end{array}$$

Therefore $$yA\rho_{Ti} / x_o A\rho_{TiO_2} = \frac{47.90}{79.90}$$

$$y = \frac{47.90 \text{ X } 4.06}{79.90 \text{ X } 4.43} = 0.55x_o$$

For the growth of TiO_2 film x_o on a layer of Ti-piece, the consumed thickness of its layer is $0.55\ x_o$

Find x_o by weighting the Ti-piece

w_1 = weight of Ti-piece before thermal oxidation, gm

w_2 = weight of Ti-piece after thermal oxidation, gm

y_o = the thickness of Ti-piece before thermal oxidation, cm

$$w_1 = \rho_{Ti} A y_o$$

and $$w_2 = \rho_{Ti} A\ (y_o - y) + \rho_{TiO_2} A\ x_o$$

Thus $$w_2/w_1 = 1-\left[0.55-4.06/4.43\right] x_o/y_o$$

$$x_o = \left[\frac{w_2}{w_1} - 1\right] 2.73\ y_o$$

The average thickness of Ti sheet before thermal oxidation, y_o is about 0.0103 + 0.0002 cm (by micrometer)

$$x_o = \frac{w_2}{w_1} -1 \quad 2.73 \text{ X } 0.0103$$

$$x_o = 0.028 \left[\frac{w_2}{w_1} - 1\right] \quad \text{cm .....B.1.2}$$

The other thickness dertermination through weighting, using the weight of oxygen in TiO_2 film calculated the thickness of x_o

$$\Delta w = w_1-w_2 = O_2, \text{ consumed}$$

From Eq.6.2.1, the consumed oxygen is 32 gm, TiO_2 growth on Ti sheet is $x_o A \rho_{TiO_2}$ Thus;

$$\frac{\Delta w \text{ X } 79.90}{32} = x_o' A \rho_{TiO_2}$$

and gives $$x_o' = 0.62 \quad w/A \quad \text{cm .....B.1.3}$$

Assume thickness of TiO_2 film on both sides of the piece have same values. Thus TiO_2 thickness of electrode is a half of x_o

$$x_1 = (x_o/2) \text{ X } 10^4$$

$$x_2 = (x_o'/2) \text{ X } 10^4$$

where x_o and x_o' are calculated from Eq.B.1.2 and B.1.3 respectively.

The weights of w_1 and w_2 are measured by electronic balance,Sartorius 1201. For five times of weighting of each samples, their average values are shown in Table 5.2.1a and 5.2.1b. The length and width of Ti sheet are measured by stainless ruler, Rumaj. Error of all values, the calculation is shown in Appendix B.2.

B.2 Calculation of errors

The error of weights (by Sartorius 1201), error is + 0.0002, the standard deviation, calculated from ten times of weighting for three samples (in Table B.1a).

Table B.2a Weights of three samples of titanium pieces

Sample	S_1	S_2	S_3
weight	0.2463	0.2536	0.2635
	0.2466	0.2539	0.2635
	0.2468	0.2539	0.2633
	0.2467	0.2538	0.2633
	0.2466	0.2538	0.2634
	0.2464	0.2537	0.2632
	0.2464	0.2540	0.2634
	0.2468	0.2537	0.2634
	0.2468	0.2534	0.2635
	0.2466	0.2538	0.2633
weight(av.)	0.2466	0.2538	0.2634
S.D.*	0.0002	0.0002	0.0001

*S.D. (standard divation) equals $(\Sigma X^2 - (\Sigma X)^2/n)/n$

In the same way, the error of titanium thickness is the standard deviation of sample thickness by random measurement (see Table B.2b)

Table B.2b. Thickness of titanium piece (10 X 15 cm)

Thickness	inch.	cm
	0.0041	0.0104
	0.0040	0.0102
	0.0042	0.0107
	0.0040	0.0102
	0.0040	0.0102
	0.0041	0.0104
	0.0040	0.0102
	0.0042	0.0107
	0.0041	0.0104
	0.0040	0.0102

The average thickness is 0.0103 cm. and the standard deviation is 0.0002.

Another errors are calculated by Eq. B.2.1 and Eq. B.2.2,

if $X = A \times B$ or A/B

then $\Delta X/X = \Delta A/A + \Delta B/B$ ..... Eq. B.2.1

or

if $X = A + B$ or $A-B$

then $\Delta X = \Delta A + \Delta B$ ..... Eq. B.2.2

where ΔX, ΔA and ΔB are errors of X, A and B respectively.

An error of oxide thickness x_o is functional of ρ_{TiO_2}, ρ_{Ti}, w_1,

w_2, y_o and A. The ρ_{Ti} of 4.51 gm/cc from the handbook,(96) it is compared with ρ_{Ti} by estimation in the experiment (the sixth column of Table 5.2.1a), about 4.34 gm/cc. Thus the exact value for Ti-piece is not proved and the error may be about 0.09 gm/cc for the range of 4.51 to 4.34 gm/cc,* For ρ_{TiO_2} of 4.22 gm/cc, it must be the crystal form, but thin film TiO_2 by thermal oxidation should be of polycrystal form.(33) For different forms of TiO_2, the density are in the range of 3.9 to 4.22 gm/cc,(19) thus the average density is 4.06 gm/cc. The ρ_{TiO_2} of thin film may be 4.06 gm/cc and the error is about 0.16 gm/cc.

For the lengh and width of Ti-pieces, their error are estimated from scale of a stainless ruler, minimum value of measurement by the ruler is 0.10 cm, then the given error is about 0.10 cm and the error of area is 0.50 cm^2 for 2X3 cm size or 0.40 cm^2 for 2X2 cm size, by calculation from Eq. B.2.1. After Ti-sheet heated, the oxide film area is decreased by holder (see Figure 5.1.1a) for formation of TiO_2 in fire. This area is approximately 0.04 cm^2, so that the total error of area A may be 0.54 cm^2 (0.50+0.04).

Therefore, the orror calculation of X_o is obtained as follows:

$$\Delta x_o/x_o = \Delta\rho_{Ti}/\rho_{Ti} + \Delta\rho_{TiO_2}/\rho_{TiO_2} + \Delta w_1/w_1 + \Delta w_2/w_2 + \Delta y_o/y_o$$

and $$\Delta x'_o/x'_o = \Delta\rho_{TiO_2}/\rho_{TiO_2} + \Delta(\Delta w)/w + \Delta A/A$$

where $$\Delta w_1 = \Delta w_2 = 0.0002 \text{ gm}$$

$$\Delta y_o = 0.0003 \text{ cm}$$

$$(\Delta w_1) = \Delta w_1 + \Delta w_2 = 0.0004 \text{ gm}$$

$$\Delta A = 0.54 \ \text{cm}^2$$

$$\Delta \rho_{Ti} = 0.09 \ \text{gm/cc}$$

$$\Delta \rho_{TiO_2} = 0.16 \ \text{gm/cc}$$

Therefore, $\Delta x_o/x_o = 0.09/4.43+0.16/4.06+0.0002/w_1+0.0002/w_2+0.0003/0.0103$

$$= 0.35 + 0.0002 \left[\frac{1}{w_1} + \frac{1}{w_2}\right] \simeq 0.35$$

and $\Delta x_o'/x_o' = 0.16/4.06 + 0.0004/\Delta w + 0.54/A$

$$= 0.039 + 0.0004/\Delta w + 0.54/A$$

Table 5.2.1 shows all values of Ti-sheets to be TiO_2 electrodes, the TiO_2 thin film thickness is the average value by estimation from x_o and x_o'; $x_{av} = (x_o+x_o')/2$.

B.3 Tests of conduction in TiO_2 electrodes.

Low resistance of a junction of TiO_2 film and copper wire through indium contact, it is a good electrode, little valtage drop in this junction. A simple test of good connection copper wire and TiO_2 electrode by measuring the resistance, between two points on TiO_2 electrode, one is at copper wire and the other Ti-sheet (its surface was held by holder in flame, however TiO_2 formation was found), the Ti-piece is conductor too, as shown in Figure B.3. The low resistance ($\Omega \rightarrow 0$) of the electrode is very good contact or connection. TiO_2 electrodes of group A, B and C, their resistance of these tests are in Table B.3. The average of resistance is about 5 Ω, it may be a junction resistance or an indication some indium oxidized.

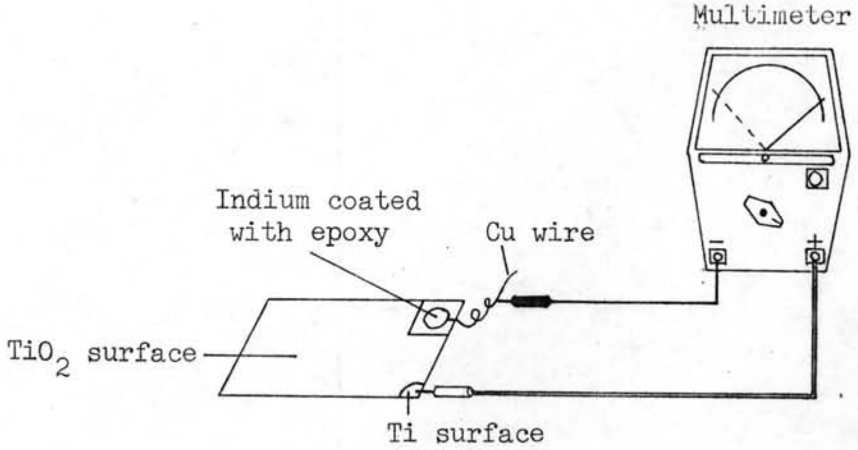


Figure B.3 Testing contact of copper wire on TiO_2 surface.

Table B.3 Resistance valves of TiO_2 electrodes in the tests of contact indium and connecting with copper wire

Electrode	Resistance (ohm)	Electrode	Resistance (ohm)
A_1	2.5	B_3	5.0
A_2	2.3	C_1	5.2
A_3	3.5	D_1	5.2
B_1	3.2	D_3	5.5
B_2	5.4	D_4	5.0

B.4 Calculation of Photocell Efficiencies

The no-voltage biased photocell, sunlight conversion efficiencies is estimated by equation of η_1, η_2 or η_5. The energy output of photocell (as hydrogen gas) in Eq. 4.1.16, is estimated by: 3.54 r, where r the amount of hydrogen (cm^3 H_2 hr^{-1}) gereration. The 3.54 term is derived from the heat of combustion of water at 25°c, as follows

$$\begin{aligned}\Delta H \text{ of hydrogen} &= 68 \text{ kcal/mole} \\ &= 68 \text{ kcal}/22400 \text{ cm}^3 H_2 \\ &= \frac{68 \times 4.2 \times 1000}{3600 \times 22400} \text{ J hr/cm}^3\ H_2 \\ &= 3.54 \text{ mW hr/cm}^3 H_2\end{aligned}$$

Thus, the energy output of photocell is 3.54 r mW/cm^2

For the input energy of sunlight radiation is defined in the intensity (mW/cm^2) term, in the experiment it is measured by a pyranometer (EKO Model MS-4), with sensitivity 6.0 $\text{mV/cal cm}^{-2}\text{min}^{-1}$ and error 12 % (less than the actual values by calibration with Kipp & Zonen CM6 and Solarimeter Integrator CC2 instruments). The instrument is connected with a digital voltmeter for intensity measurement. V_I is millivolt of the voltmeter and the intensity of sunlight, Ia (mW/cm^2) is given by :

$$\begin{aligned}\text{Ia} &= \frac{4.2 \times 10^3}{6.0 \times 60 \times 0.88} V_I \\ &= 1.32\ V_I \text{ mW/cm}^2\end{aligned}$$

Thus, the input of photocell is 1.32 V_I mW/cm^2.

APPENDIX C

EXPERIMENTAL DATA AND RESULTS

Table C.1

Experimental data and results

TiO_2 electrode (D) area 1.8 cm^2, Pt electrode (Pt3) area 0.28 cm^2

Temperature ∿ 29°c

V_3 mV	I $\mu A/cm^2$	V_{TiO_2-SCE} V	V_3 mV	I $\mu A/cm^2$	V_{Pt-SCE} V
0.0	0.0	-0.02	0.0	0.0	-0.05
0.6	6.7	-0.01	0.5	5.9	-0.15
1.3	14.4	0.06	1.3	14.4	-0.20
2.2	24.4	0.12	2.1	23.8	-0.29
4.0	44.4	0.22	3.8	43.2	-0.37
6.0	66.7	0.35	5.7	64.2	-0.40
6.7	74.4	0.45	6.5	72.9	-0.40
7.3	81.1	0.55	7.2	80.2	-0.40
7.8	86.7	0.60	7.7	85.3	-0.42
8.7	96.7	0.80	8.6	96.1	-0.42
9.0	100.0	0.90	8.9	98.7	-0.42
9.7	107.8	1. 0	9.5	106.3	-0.44
10.6	117.8	1.20	10.4	116.5	-0.45

Table C.2

Experiment data and results

TiO_2 electrode (A) area 1.8 cm^2, Pt electrode (Pt3) area 0.28 cm^2

Temperature ∿ 30 °c

	l_1 = 35 cm		l_2 = 20 cm		l_3 = 10 cm	
V_2	V_3	I	V_3	I	V_3	I
V	mV	$\mu A/cm^2$	mV	$\mu A/cm^2$	mV	$\mu A/cm^2$
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.1	1.1	0.2	2.2	0.1	1.1
0.4	0.4	4.4	0.5	5.5	0.5	5.5
0.6	0.6	6.7	0.9	10.0	1.0	11.1
0.8	0.6	6.7	1.2	13.3	1.6	17.8
1.0	0.7	7.8	1.4	15.5	2.0	22.2
1.2	0.8	8.9	1.6	17.8	2.4	24.4
1.4	0.9	10.0	1.7	18.9	2.7	30.0
1.6	0.9	10.0	1.8	20.0	3.0	34.4
1.8	1.0	11.1	2.0	22.2	3.1	34.4
2.0	1.1	12.2	2.1	23.3	3.3	36.7
2.2	1.4	15.5	2.2	24.4	3.6	40.0

l = a distance of the splot light from a TiO_2 surface

Table C.3

Experimental data and results

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrodes under sunlight illumination

Electrode	A1	A2	A3	B1	B2	B3	C1	D1	D2	D3
Area (cm^2)	3.60	3.45	2.25	2.00	2.72	2.50	2.94	2.25	1.95	1.75

Temperature 30-31 °c

Time (min)	V_3(mV)	V_I(mV)	I_{sc}(mA/cm^2)	Ia* (mW/cm^2)	η_2%
Electrode A1					
4	30.8	6.1	0.171	80.5	0.18
5	30.8	5.9	0.177	77.9	0.19
5	30.8	6.2	0.171	81.8	0.18
average			0.173	80.0	0.18
Electrode A2					
5	25.1	6.1	0.146	80.5	0.16
5	25.3	6.5	0.144	85.8	0.14
5	28.7	6.1	0.166	80.5	0.18
average			0.152	82.2	0.16
Electrode A3					
4	18.6	6.1	0.165	80.5	0.18
4	18.5	6.1	0.164	80.5	0.17
5	19.3	6.4	0.171	84.5	0.17
average			0.167	81.8	0.17

* the calculation of Ia was in Appendix B.4

Table C.3

(continued)

Electrode B1

Time (min)	V_3 (mV)	V_I (mV)	I_{sc} (mA/cm^2)	Ia (mW/cm^2)	η_2%
3	11.6	5.9	0.116	77.9	0.13
4	11.5	5.9	0.115	77.9	0.13
5	11.8	6.0	0.118	79.2	0.13
average			0.117	77.9	0.13
Electrode B2					
4	16.5	5.8	0.121	76.5	0.14
4	17.1	6.0	0.126	79.2	0.14
4	16.3	5.5	0.120	72.6	0.14
average			0.123	76.1	0.14
Electrode B3					
3	15.0	4.5	0.110	71.3	0.13
5	15.8	5.6	0.116	73.9	0.13
5.	15.5	5.5	0.114	72.6	0.16
average			0.115	72.6	0.14
Electrode C1					
4	23.2	5.2	0.158	68.6	0.20
5	24.7	5.8	0.168	76.5	0.19
5	24.7	5.8	0.168	77.9	0.18
average			0.162	74.3	0.19

Table C.3

(continued)

Electrode D1

Time (min)	V_3(mV)	V_I(mV)	I_{sc} (mA/cm^2)	I_a(mW/cm^2)	η_2%
3	20.3	6.1	0.180	80.8	0.19
5	20.5	6.0	0.176	79.2	0.19
5	20.4	6.0	0.181	79.2	0.20
average			0.179	79.7	0.19
Electrode D2					
4	17.5	6.0	0.179	79.2	0.19
4	17.7	6.1	0.182	80.5	0.20
5	17.8	6.1	0.183	80.5	0.20
average			0.181	80.0	0.20
Electrode D3					
4	14.8	6.0	0.169	79.2	0.18
5	14.8	5.9	0.170	77.9	0.19
5	15.5	6.0	0.178	79.2	0.19
average			0.172	78.7	0.19

Table C.4

Experimental data and results

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrodes (the area in Table C.3) under sunlight illumination

Temperature 29-32 °c

Electrode		A1	B2	D1
Time (min)	V_I (mV)	V_3 (mV)	V_3 (mV)	V_3 (mV)
2	3.9	11.2	8.0	13.6
3	4.0	12.1	10.2	14.4
3	4.0	11.7	10.5	12.5
2	4.2	12.4	10.5	15.3
3	4.0	10.1	10.2	16.3
3	4.2	12.2	10.2	14.4
	Ia (mW/cm^2)	I_{sc} (mA/cm^2)	I_{sc} (mA/cm^2)	I_{sc} (mA/cm^2)
	51.5	0.062	0.059	0.121
	52.8	0.067	0.075	0.128
	52.8	0.065	0.077	0.111
	55.4	0.069	0.077	0.136
	52.8	0.056	0.075	0.145
	55.4	0.068	0.075	0.128
average	53.5	0.065	0.073	0.123
	η_2%	0.11	0.12	0.21

Table C.4

(contiuned)

Time range of V_3 measurement was about 3 min

Electrode	A1	A2	A3	B3	D1	D2
V_I (mV)			V_3 (mV)			
5.1	27.7	20.6	15.3	16.9	17.0	16.3
5.0	27.3	20.5	14.7	16.5	17.4	16.2
5.0	27.1	20.6	15.6	16.5	17.7	16.1
5.1	26.0	19.4	15.1	16.0	16.2	15.7
5.0	25.8	19.3	15.0	16.9	16.0	16.8
I_a (mW/cm^2)			I_{sc} (mA/cm^2)			
67.3	0.153	0.119	0.136	0.130	0.150	0.167
66.7	0.152	0.118	0.130	0.147	0.155	0.166
66.0	0.150	0.119	0.138	0.147	0.157	0.165
67.3	0.144	0.112	0.134	0.142	0.144	0.161
66.0	0.143	0.112	0.133	0.141	0.142	0.172
average 66.5	0.148	0.116	0.134	0.141	0.150	0.166
η_2%	0.19	0.15	0.18	0.18	0.20	0.22

Table C.5

Experimental data and results

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrodes under spot light illumination

Electrode	A1	A2	A3	B1	B2	B3	D1	D2	D3
Area (cm^2)	4.9	5.0	5.0	4.6	5.0	4.8	3.0	3.2	3.0
I_d ($\mu A/cm^2$)	2.6	3.0	3.9	3.0	3.8	3.1	2.7	3.0	3.0

Temperature 28 - 29 °c

Time	V_3 (mV)								
(min)	A1	A2	A3	B1	B2	B3	D1	D2	D3
5	2.89	2.55	2.85	3.11	3.6	1.91	1.33	1.26	1.14
10	2.74	2.50	2.80	3.20	3.5	1.85	1.20	1.22	1.12
Time	I_{sc} ($\mu A/cm^2$)								
5	11.8	10.2	11.4	13.9	14.5	15.9	17.7	15.8	15.2
10	11.2	10.0	11.2	13.5	14.5	15.4	16.1	15.3	14.9

Table C.6

Experimental data

Pt electrode (Ptl) area 0.99 cm^2

Photocells with a voltage - bias.

Temperature 29 - 31 °c

TiO_2 electrode (A+B+D) area 25.5 cm^2

V_b (V)	0.2	0.4	0.6	0.8	1.0	V_I (mV)
	9.1	12.8	15.3	20.4	25.5	3.4
	9.0	12.0	16.6	21.7	25.4	3.5
V_3 (mV)	9.0	14.1	18.4	21.6	24.2	3.4
	9.1	14.0	18.4	20.5	25.6	3.5
	9.1	14.0	18.3	20.4	24.2	3.5

V_b (V)	0.2	0.4	0.6	0.8	1.0	V_I (mV)
	19.1	20.4	28.1	33.1	36.9	5.4
	15.3	21.6	28.0	31.9	34.4	5.4
V_3 (mV)	15.3	21.7	28.0	31.9	35.7	5.4
	14.0	21.7	28.0	33.2	35.7	5.3
	14.0	21.6	28.0	33.1	36.9	5.3
	14.0	21.6	28.1	33.1	35.7	5.3

Table C.6

(continued)

Experimental results

Electrodes A+B+C , area 25.5 cm^2

V_b (V)	0.2	0.4	0.6	0.8	1.0
I_c (mA/cm^2)	0.071	0.10	0.12	0.16	0.20
	0.071	0.11	0.13	0.17	0.20
	0.071	0.11	0.14	0.17	0.19
	0.071	0.11	0.14	0.16	0.20
	0.071	0.11	0.14	0.16	0.19

V_b (V)	0.2	0.4	0.6	0.8	1.0	Ia (mW/cm^2)
η_4 (%)	0.16	0.18	0.17	0.15	0.10	44.9
	0.16	0.20	0.18	0.16	0.10	46.2
	0.16	0.20	0.20	0.16	0.10	44.9
	0.16	0.20	0.19	0.15	0.10	46.2
	0.16	0.20	0.19	0.18	0.09	46.2
average	0.16	0.20	0.19	0.15	0.10	45.7

Table C.6

(continued)

Experimental results

Electrodes A+B+C , area 25.5 cm^2

V_b(V)	0.2	0.4	0.6	0.8	1.0
I_c(mA/cm^2)	0.15	0.16	0.22	0.26	0.29
	0.12	0.17	0.22	0.25	0.27
	0.12	0.17	0.22	0.25	0.28
	0.11	0.17	0.22	0.26	0.28
	0.11	0.17	0.22	0.26	0.29
	0.11	0.17	0.22	0.26	0.28

V_b(V)	0.2	0.4	0.6	0.8	1.0	Ia (mW/cm^2)
η_4(%)	0.22	0.18	0.19	0.15	0.09	71.3
	0.17	0.19	0.19	0.15	0.09	71.3
	0.17	0.19	0.19	0.15	0.09	71.3
	0.16	0.20	0.20	0.16	0.09	69.9
	0.16	0.20	0.20	0.16	0.09	69.9
	0.16	0.20	0.20	0.16	0.09	69.9
average	0.17	0.19	0.20	0.16	0.09	70.6

Table C.7

Experimental data and results

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrode in photocell under spot light

Electrode	A1 = 4.5 cm^2		B2 = 4.4 cm^2		D1 = 3.0 cm^2	
Vb(V)	V_3(mV)	I($\mu A/cm^2$)	V_3(mV)	I($\mu A/cm^2$)	V_3(mV)	I($\mu A/cm^2$)
0.2	0.25	1.1	1.96	8.9	1.15	7.7
0.4	2.50	11.1	3.41	15.5	2.51	16.7
0.6	4.00	17.8	7.32	33.3	4.83	32.2
0.8	4.99	22.2	9.53	43.3	5.83	38.9
1.0	5.49	24.4	11.48	52.2	8.70	54.4

Electrode	i (1.23 - V_b)		
Vb(V)	A1	B2	D1
0.2	1.13	9.17	7.93
0.4	9.21	12.86	13.86
0.6	*11.21	*20.98	*20.29
0.8	9.54	18.62	16.73
1.0	5.61	12.00	12.51

* The maximum values of i(1.23-V_b) terms.

Table C.8

Experimental data and results

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrode A in photocell for hydrogen production

l = distance between the TiO_2 and solution surfaces.

l	sunlight illumination	spot light illumination
(cm)	I_{sc} (mA)	I_{sc} (μA)
0.5	1.6	19
1.5	1.5	18
2.0	-	17
2.5	1.4	-
3.0	1.3	17
5.5	-	14

TiO_2 electrode A area 6.6 cm^2

i) lmg/ 50 ml KCl solution

Time (min)	V_I (mV)	I_a (mW/cm^2)	cc of H_2	r (cc/cm^2hr)	η_1 %*
0	4.6	60.7	-	-	-
5	4.6	60.7	0.045	0.034	0.20
10	4.6	60.7	0.105	0.041	0.24
25	4.5	60.4	0.125	0.041	0.24
38	4.5	60.4	0.163	0.039	0.23
	average	60.5		0.039	0.23

* the calculation of η_1 was in Appendix B.4

Table C.8

(continued)

ii) 2 mg/50 ml KCl solution

Time(min)	V_I	Ia(mW/cm^2)	cc of H_2	r(cc/cm^{2}hr)	η_1(%)
0	4.6	60.7	-	-	-
5	4.5	60.0	0.015	0.023	0.14
10	4.5	60.0	0.039	0.035	0.21
28	4.7	62.0	0.117	0.038	0.22
	average	60.3		0.034	0.20

iii) 4 mg/50 ml KCl solution

Time(min)	V_I(mV)	Ia(mW/cm^2)	cc of H_2	r(cc of cm^{2}hr)	η_1(%)
0	4.6	60.7	-	-	-
14	4.5	59.4	0.04	0.026	0.15
28	4.2	55.4	0.08	0.026	0.16
35	4.5	59.4	0.095	0.025	0.16
	average	59.3		0.026	0.16

Table C.9

Experimental data and results

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrodes under sunlight illumination

Time 9:30 - 10:30 a.m.

TiO_2 electrode A(A1+A2) area 6.6 cm^2

Temperature 29-31 °c

Time (min)	V_I (mV)	cc of H_2	Ia (mW/cm^2)	r (cc/cm^2hr)
0	4.9	-	64.7	-
11	4.9	0.035	64.7	0.035
30	5.0	0.039	66.0	0.039
54	5.1	0.039	67.3	0.039
60	5.1	0.042	67.3	0.042
		average	65.2	0.039

Time 10:00 - 11:00 a.m.

TiO_2 electrode B(B2+B3) area 6.9 cm^2

Temperature 29-30 °c

Time (min)	V_I (mV)	cc of H_2	Ia (mW/cm^2)	r (cc/cm^2hr)
0	4.9	-	64.7	-
11	5.0	0.03	66.0	0.026
21	5.1	0.065	67.3	0.027
31	5.0	0.090	66.0	0.025
40	5.1	0.120	67.3	0.026
		average	65.5	0.026

Table C.9

(continued)

TiO_2 electrode D(D1+D2+D3) 5.5 cm^2

Time 9:30 - 10:30 a.m. (23 April 1982)

Temperature 29-31 °c

Time (min)	V_I (mV)	cc of H_2	Ia(mW/cm^2)	r (cc/cm^2hr)
0	4.9	-	64.7	-
14	5.0	0.10	66.0	0.048
32	5.1	0.22	67.3	0.075
43	5.1	0.29	67.3	0.073
52	5.2	0.35	68.6	0.074
		average	66.7	0.075

Table C.10

Experimental data

Pt electrode (Pt3) area 0.28 cm^2

9:30 - 10:30 a.m.

TiO_2 electrode A(A1+A2+A3) area 7.2 cm^2

Time (min)	V3(mV)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
5	30.6	5.4	0.020	71.3
8	30.2	5.4	0.030	71.3
10	29.5	5.5	0.040	72.6
15	29.2	5.5	0.060	72.6
11:30 - 12:00 a.m.				
3	36.4	5.9	0.015	77.9
5	36.5	5.9	0.030	77.9
10	36.6	6.0	0.055	79.2
12	36.3	5.9	0.075	77.9
1:30 - 2:30 p.m.				
5	28.4	5.3	0.015	69.9
10	27.4	5.2	0.032	68.6
15	27.0	5.3	0.050	69.9
20	25.9	5.2	0.065	69.6
2:30 - 3:30 p.m.				
5	20.2	4.6	0.018	60.7
8	19.4	4.5	0.022	59.4
15	18.4	4.5	0.040	59.4
20	17.3	4.3	0.052	56.7

Table C.10

(continued)

Experimental results

TiO_2 electrode A

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_1(%)
71.3	0.085	0.034	0.17
71.3	0.084	0.032	0.16
71.7	0.082	0.034	0.17
71.9	0.081	0.033	0.16
71.6	0.086	0.033	0.17
77.9	0.101	0.042	0.19
77.9	0.101	0.050	0.23
78.3	0.100	0.046	0.21
78.2	0.101	0.052	0.24
78.0	0.101	0.048	0.22

Table C.10

(continued)

Experimental results

TiO_2 electrode A

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_1(%)
69.9	0.079	0.025	0.13
69.3	0.076	0.027	0.16
69.5	0.075	0.028	0.16
69.5	0.072	0.027	0.17
69.5	0.076	0.027	0.16

60.7	0.056	0.020	0.12
60.1	0.054	0.023	0.14
59.8	0.051	0.022	0.13
59.1	0.048	0.022	0.13
59.9	0.052	0.022	0.13

Table C.11

Experimental data

Pt electrode (Pt3) area 0.28 cm^2

11:30 - 12:30 a.m.

TiO_2 electrode D + C area 7.2 cm^2

Time (min)	V_3 (mV)	V_3 (mV)	H_2volume(cc)	Ia (mW/cm^2)
6	40.2	5.6	0.050	73.9
15	41.0	5.6	0.135	73.9
27	39.8	5.7	0.245	75.2
33	38.0	5.7	0.295	75.2
1:30 - 2:30 p.m.				
8	31.3	5.0	0.030	66.0
11	27.5	4.9	0.050	14.7
23	27.5	4.8	0.095	63.3
31	27.0	4.8	0.130	63.3
2:30 - 3:00 p.m.				
6	30.5	4.5	0.02	59.4
15	27.5	4.5	0.058	59.4
27	26.0	4.3	0.115	56.7
33	25.0	4.2	0.130	55.4
3:00 - 4:00 p.m.				
10	20.0	3.8	0.025	50.1
17	19.5	3.5	0.045	46.2
30	18.6	3.5	0.085	46.2

Table C.11

(continued)

Experimental results

TiO_2 electrode D + C_1

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2 hr)	η_1(%)
73.9	0.112	0.070	0.34
73.9	0.114	0.075	0.36
74.3	0.110	0.076	0.36
74.6	0.105	0.075	0.36
74.2	0.110	0.074	0.36
66.0	0.087	0.033	0.18
65.4	0.076	0.038	0.21
64.7	0.076	0.034	0.19
64.4	0.075	0.035	0.19
65.1	0.078	0.035	0.19
59.4	0.084	0.030	0.18
59.4	0.076	0.032	0.19
58.5	0.072	0.035	0.21
57.7	0.069	0.033	0.20
58.8	0.075	0.033	0.20
50.1	0.066	0.021	0.14
48.1	0.056	0.022	0.16
47.5	0.053	0.024	0.18
48.5	0.050	0.022	0.17

Table C.12

Experimental data

Pt electrode (Ptl) area 0.99 cm^2

TiO_2 electrode area 33.9 cm^2

11:30 -12:30 a.m.

Time(min)	V3(mV)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
3	162.7	5.9	0.085	77.9
8	161.0	6.0	0.245	79.2
15	157.6	6.0	0.455	79.2
28	159.3	6.1	0.870	80.5
2:00 - 3:00 p.m.				
5	98.3	4.2	0.065	55.4
10	96.6	4.1	0.140	54.1
15	91.5	4.0	0.200	52.8
25	84.8	3.9	0.340	51.4
3:30 - 4:30 p.m.				
9	79.2	2.6	0.090	34.3
16	78.4	2.5	0.160	33.0
18	69.3	2.5	0.180	33.0
32	67.7	2.4	0.220	31.7

Table C.12

(continued)

Results

Iav(mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^{2}hr)	η_1(%)
77.9	0.096	0.050	0.23
78.6	0.095	0.053	0.24
78.8	0.093	0.054	0.24
79.2	0.094	0.055	0.25
78.6	0.095	0.054	0.24
55.4	0.058	0.023	0.15
54.8	0.057	0.025	0.16
54.1	0.054	0.024	0.16
53.4	0.050	0.024	0.16
54.4	0.055	0.024	0.16
34.3	0.047	0.018	0.19
33.7	0.046	0.018	0.19
33.4	0.041	0.018	0.19
33.0	0.040	0.012	0.13
33.6	0.044	0.017	0.18

Table C.13

Experimental data

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrode area 21.1 cm^2

Electrode	Area (cm^2)	Electrode	Area (cm^2)
A1	3.15	D1	1.69
A2	3.05	D2	2.35
A3	2.64	D3	2.65
B1	3.30	E	2.30

Time (min)	V_I (mV)	H_2 volume (cc)	Temp (°c)	Ia (mW/cm^2)
0	5.8	-	16	76.5
6	5.8	0.115	17	76.5
10	5.9	0.195	18	77.9
14	5.9	0.275	17	77.9
18	5.5	0.340	17	76.5

Results

Temp (°c)	Iav (mW/cm^2)	r (cc/cm^2hr)	η_1 (%)
16	76.5	-	-
17	76.5	0.054	0.25
18	76.5	0.056	0.26
17	76.8	0.056	0.26
17	76.7	0.054	0.25
17	76.6	0.054	0.25

Table C.13

(continued)

Experimental data

Time (min)	V_I (mV)	H_2 volume (cc)	Temp (°c)	Ia (mW/cm^2)
0	5.0	-	17	66.0
2	5.1	0.028	18	67.3
4	5.1	0.058	18	67.3
6	5.2	0.088	19	68.6
8	5.0	0.118	19	66.0
15	5.1	0.225	20	67.3

Results

Temp (°c)	Iav (mW/cm^2)	r ($cc/cm^2 hr$)	η_1 (%)
17	66.0	-	-
18	66.6	0.040	0.21
18	66.9	0.041	0.22
19	67.3	0.042	0.22
19	67.1	0.042	0.22
20	67.1	0.041	0.22
19	66.8	0.041	0.22

Table C.13

(continued)

Experimental data

Time (min)	V_I (mV)	H_2 volume (cc)	Temp (°c)	Ia (mW/cm^2)
0	4.5	-	13	59.4
2	4.5	0.025	11	59.4
5	4.5	0.055	12	58.4
9	4.4	0.115	11	58.1
16	4.4	0.220	12	58.1

Results

Temp (°c)	Iav (mW/cm^2)	r (cc/cm^{2}hr)	η_1 (%)
13	59.4	-	-
11	59.4	0.035	0.21
12	59.4	0.031	0.19
11	59.1	0.036	0.21
12	58.9	0.039	0.23
12	59.2	0.035	0.21

Table C.13

(continued)

Experimental data

Time (min)	V_I (mV)	H_2 volume (cc)	Temp (°c)	Ia (mW/cm^2)
0	4.2	-	13	55.4
5	4.2	0.025	13	55.4
9	4.1	0.060	12	54.1
12	4 0	0.095	12	52.8
15	4.0	0.115	12	52.8
18	4.0	0.145	12	52.8

Results

Temp (°c)	Iav (mW/cm^2)	r (cc/cm^2hr)	η_1 (%)
13	55.4	-	-
13	55.4	0.014	0.09
12	54.9	0.019	0.12
12	54.4	0.021	0.14
12	54.1	0.022	0.14
12	53.9	0.023	0.15
12	54.7	0.020	0.13

Table C.14

Experimentat data

Pt electrode (Pt3) area 0.28 cm^2

TiO_2 electrode area 21.1 cm^2 (in Table C.13)

Time (min)	V_I (mV)	H_2 volume (cc)	Temp (°c)	Ia (mW/cm^2)
0	5.8	-	34	76.5
2	5.8	0.030	34	76.5
5	5.9	0.080	34	77.9
10	6.0	0.170	34	79.2
15	6.0	0.270	35	79.2
18	6.0	0.305	35	79.2

Results

Temp (°c)	Iav (mW/cm^2)	r ($cc/cm^2 hr$)	η_1 (%)
34	76.5	-	-
34	76.5	0.043	0.20
34	77.0	0.045	0.21
34	77.5	0.048	0.22
35	77.9	0.051	0.23
35	78.1	0.048	0.22
34	77.2	0.047	0.22

Table C.14

(continued)

Experimental data

Time (min)	V_I(mV)	H_2 volume	Temp (°c)	Ia(mW/cm^2)
0	5.0	-	33	66.0
2	5.0	0.030	33	66.0
6	5.1	0.090	33	67.3
10	5.1	0.155	33	67.3
15	5.1	0.230	33	67.3

Results

Temperature	Iav (mW/cm^2)	r (cc/cm^{2}hr)	η_1%
33	66.0	-	-
33	61.0	0.043	0.23
33	66.3	0.043	0.23
33	66.5	0.044	0.23
33	66.6	0.044	0.23
33	66.2	0.043	0.23

Table C.14

(continued)

Experimental data

Time (min)	V_I (mV)	H_2 volume	Temp (°c)	Ia (mW/cm^2)
0	4.3	-	32	56.7
5	4.4	0.055	32	58.1
7	4.4	0.835	32	58.1
9	4.2	0.110	33	55.4
11	4.2	0.135	33	55.4
15	4.2	0.180	32	55.4

Results

Temp (°c)	Iav (mW/cm^2)	r (cc/cm^2hr)	η_1 (%)
32	56.7	-	-
32	57.4	0.032	0.20
32	57.6	0.034	0.21
33	56.0	0.035	0.22
33	56.7	0.035	0.22
32	56.5	0.034	0.21
32	57.0	0.034	0.21

Table C.14

(continued)

Experimental data

Time (min)	V_I (mV)	H_2 volume (cc)	Temp (°c)	Ia (mW/cm^2)
0	3.9		32	51.5
10	3.9	0.055	32	51.5
15	3.7	0.125	32	48.8
18	3.5	0.150	32	46.2

Results

Temp (°c)	Iav (mW/cm^2)	r (cc/cm^{2}hr)	η_1%
32	51.5	-	-
32	51.5	0.016	0.11
32	50.6	0.024	0.16
32	49.5	0.024	0.17
32	50.8	0.021	0.14

Table C.15

Experimental data

Pt electrode (Pt3) area 0.28 cm^2

Non-stirred Solution

TiO_2 electrode area 11.6 cm^2

Electrode	Area(cm^2)	Electrode	Area(cm^2)
D1	1.50	E2	1.25
D2	1.50	E3	1.50
D3	1.55	E4	1.50
E1	1.40	E5	1.40

Time(min)	V_I (mV)	H_2volume(cc)	Ia(mW/cm^2)
0	5.2	-	68.6
6	6.6	0.03	87.1
10	6.7	0.025	88.4
15	4.8	0.130	63.3
21	6.0	0.200	79.2
27	4.8	0.280	63.3

Table C.15

(Continued)

TiO_2 electrode area 25.5 cm^2

Electrode	Area(cm^2)	Electrode	Area(cm^2)
A1	3.60	E1	1.40
A2	3.55	E2	1.25
A3	3.20	E3	1.50
C1	2.15	E4	1.50
D1	1.50	E5	1.40
D2	1.50	E6	1.40
D3	1.55		

Time(min)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
0	5.5	–	72.6
2	5.4	0.015	71.3
4	5.5	0.030	72.6
6	5.5	0.050	72.6
8	5.4	0.070	71.3
10	5.4	0.085	71.3
15	5.4	0.125	71.3

Table C.15

(Continued)

TiO_2 electrode area 33.9 cm^2

Electrode	Area(cm^2)	Electrode	Area(cm^2)
A1	3.60	E4	1.50
A2	3.54	E5	1.40
A3	3.20	E6	1.40
B1	3.00	E7	1.40
C1	2.15	E8	1.30
E1	1.40	E9	1.30
E2	1.25	E10	1.40
E3	1.50		

Time(min)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
0	5.5	-	72.6
2	5.5	0.015	72.6
6	5.5	0.055	72.6
9	5.5	0.085	72.6
14	5.6	0.120	71.3
16	5.4	0.145	71.3
18	5.5	0.170	72.6
20	5.5	0.190	72.6

Table C.15

(Continued)

Experimental results

TiO_2 electrode area 11.6 cm^2

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
68.6	-	-
77.9	0.025	0.11
81.4	0.044	0.20
76.9	0.045	0.21
77.3	0.049	0.22
75.0	0.053	1.25
76.2	0.043	0.20

TiO_2 electrode area 25.5 cm^2

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
72.6	-	-
71.9	0.018	0.09
72.2	0.018	0.09
72.3	0.020	0.10
72.1	0.021	0.10
72.0	0.020	0.10
71.9	0.020	0.10
72.1	0.020	0.10

Table C.15

(Cintinued)

TiO_2 electrode area 33.9 cm^2

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
72.6	-	-
72.6	0.015	0.07
72.6	0.022	0.11
72.6	0.024	0.12
72.3	0.025	0.12
72.2	0.027	0.13
72.5	0.026	0.13
72.6	0.023	0.11

Table C.16

Experimental data

Pt electrode (Pt3) area 0.28 cm^2

Stirred solution

TiO_2 electrode area 11.6 cm^2 (Table C.15)

Time(min)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
0	6.3	-	83.1
5	6.2	0.056	81.8
10	6.2	0.125	81.8
15	5.5	0.200	72.6
20	1.7	0.255	22.4
25	6.2	0.300	81.8

TiO_2 electrode area 25.5 cm^2 (Table C.15)

Time(min)	V_I(mV)	H_2 volume (cc)	Ia(mW/cm^2)
0	4.5	-	71.3
2	5.4	0.020	71.3
4	5.4	0.045	71.3
6	5.4	0.071	71.3
8	5.5	0.096	72.6
10	5.4	0.121	71.3
19	5.3	0.230	71.3

Table C.16

(Continued)

TiO_2 electrode area 33.9 cm^2 (Table C.15)

Time(min)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
0	5.4	-	71.3
5	5.5	0.042	72.6
10	5.5	0.124	72.6
12	5.5	0.162	72.6
16	5.6	0.226	73.9
18	5.6	0.275	73.9
20	5.5	0.294	72.6

Experimetal results

TiO_2 electrode area 11.6 cm^2

Iav(mW/cm^2)	r(cc/cm^2hr)	η_1(%)
83.1	-	-
82.4	0.059	0.25
82.2	0.065	0.28
79.8	0.068	0.30
68.3	0.066	0.34
70.6	0.062	0.31
77.7	0.064	0.30

Table C.16

(Continued)

TiO_2 electrode area 25.5 cm^2

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
71.3	-	-
71.3	0.023	0.11
71.3	0.026	0.13
71.6	0.028	0.14
71.6	0.028	0.14
71.5	0.028	0.14
71.4	0.027	0.13
71.4	0.027	0.13

TiO_2 electrode area 33.9 cm^2

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
71.3	-	-
71.9	0.015	0.07
72.2	0.022	0.11
72.3	0.024	0.12
72.6	0.025	0.13
72.8	0.027	0.13
72.8	0.026	0.13
72.3	0.023	0.11

Table C.17

Experimetal data

Pt electrode (Pt3) area 0.28 cm^2

Non-biased photocells

TiO_2 electrode A area 7.2 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2 volume (cc)	Ia (mW/cm^2)
3	6.0	36.4	0.015	79.2
5	5.9	36.5	0.030	77.9
8	5.9	36.6	0.045	77.9
10	5.9	36.1	0.062	77.9
12	5.9	36.3	0.075	77.9

TiO_2 electrode B+C area 5.5 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2 volume (cc)	Ia (mW/cm^2)
4	5.5	19.3	0.012	72.6
7	5.4	18.9	0.025	71.3
9	5.3	18.0	0.032	69.9
11	5.3	18.1	0.035	69.9
13	5.5	19.3	0.042	72.6
15	5.5	19.2	0.060	72.6

Table C.17

(Continued)

TiO_2 electrode D area 5.8 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2volume (cc)	Ia (mW/cm^2)
2	5.2	37.6	0.015	68.6
5	5.0	36.6	0.035	66.0
7	4.6	32.7	0.045	60.7
9	5.0	34.9	0.055	66.0
12	5.0	35.5	0.075	66.0
14	4.9	34.6	0.085	64.7

Experimental results

TiO_2 electrode A

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_1 (%)	η_2 % (%)
78.5	0.101	0.042	0.19	0.11
78.3	0.101	0.050	0.23	0.11
78.2	0.101	0.047	0.21	0.11
78.2	0.100	0.051	0.23	0.11
78.1	0.101	0.052	0.24	0.11
78.4	0.101	0.048	0.22	0.11

Table C.17

(Continued)

TiO_2 electrode B+C

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r ($cc/cm^2 hr$)	η_1 (%)	η_2 (%)
72.6	0.070	0.033	0.16	0.08
72.6	0.070	0.039	0.19	0.08
71.6	0.065	0.039	0.19	0.08
71.3	0.066	0.025	0.12	0.08
71.5	0.070	0.035	0.17	0.08
71.6	0.070	0.043	0.21	0.08
71.9	0.069	0.036	0.17	0.08

TiO_2 electrode D

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r ($cc/cm^2 hr$)	η_1 (%)	η_2 (%)
67.3	0.130	0.077	0.40	0.14
66.9	0.126	0.072	0.38	0.16
65.3	0.113	0.055	0.30	0.15
65.7	0.120	0.063	0.34	0.16
65.8	0.122	0.065	0.35	0.16
68.3	0.119	0.063	0.34	0.16
66.0	0.122	0.066	0.35	0.16

Table C.18

Experimental data

Pt electrode (Pt3) area 0.28 cm^2

Biased photocells

TiO_2 electrode A area 7.2 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2volume (cc)	Ia (mW/cm^2)	V_b (V)
4	5.6	72.0	0.060	73.9	0.46
6	5.6	72.3	0.065	73.9	0.44
8	5.6	72.5	0.115	73.9	0.44
10	4.3	54.4	0.135	56.7	0.43
12	5.7	71.5	0.160	75.2	0.43
14	5.7	70.0	0.166	75.2	0.43

TiO_2 electrode B+C area 5.5 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2volume (cc)	Ia (mW/cm^2)	V_b (V)
4	5.6	29.0	0.02	73.9	0.47
6	5.5	28.6	0.03	72.6	0.46
8	5.5	28.6	0.035	72.6	0.44
10	5.7	29.7	0.045	78.2	0.44
14	5.4	27.7	0.065	71.3	0.43

Table C.18

(Continued)

TiO_2 electrode D area 5.8 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2volume (cc)	Ia (mW/cm^2)	V_b (V)
3	4.9	63.6	0.035	64.7	0.45
5	4.7	61.4	0.055	62.0	0.44
6	4.5	57.6	0.065	59.4	0.44
8	4.7	61.2	0.085	62.0	0.43
10	4.6	61.9	0.100	60.7	0.43
12	4.6	61.6	0.120	60.7	0.43

Note that Vb refers to Vl in Figure 5.1.5 c

Experimental results

TiO_2 electrode A

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_4 (%)
73.9	0.200	0,083	0,21
73.9	0.200	0.093	0,21
73.9	0.201	0.120	0.22
76.7	0.151	0.112	0,21
75.2	0.199	0.111	0,22
75.2	0.194	0,099	0,20
74.6	0.194	0.105	0,21

Table C.18

(Continuced)

TiO_2 electrode B+C

Iav(mW/Cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^{2}hr)	η_4(%)
73.9	0.105	0.054	0.11
72.6	0.104	0.054	0.11
72.6	0.104	0.047	0.11
75.2	0.108	0.049	0.11
71.3	0.101	0.051	0.11
72.0	0.104	0.051	0.11

TiO_2 electrode D

Iav(mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^{2}hr)	η_4(%)
64.7	0.219	0.121	0.27
62.0	0.212	0.114	0.27
59.4	0.199	0.112	0.27
62.0	0.211	0.110	0.27
60.7	0.213	0.103	0.27
60.7	0.212	0.103	0.27
62.0	0.213	0.110	0.27

Note that η_4 was calculated by Eg. 4.1.19.

Table C.19

Experimental data

TiO_2 electrode area 33.9 cm^2 (Table C.16)

Non-biased photocells

Pt3 electrode area 0.28 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2 volume (cc)	Ia (mW/cm^2)
2	5.3	81.4	0.02	69.9
5	5.4	84.7	0.055	71.3
10	5.3	79.6	0.120	69.9
12	5.3	69.5	0.140	69.9
14	5.4	67.8	0.160	71.3
16	5.3	77.9	0.180	69.9

Pt_2 electrode area 0.45 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2 volume (cc)	Ia (mW/cm^2)
2	5.3	103.4	0.02	69.9
5	5.2	101.2	0.06	68.6
10	5.2	100.3	0.145	68.6
16	5.3	100.5	0.280	69.9
18	5.2	98.5	0.300	68.6
20	5.1	91.4	0.330	67.3

Table C.19

(Continued)

Pt_1 electrode area 0.99 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2volume (cc)	Ia (mW/cm^2)
4	5.4	150.7	0.11	71.3
6	5.4	149.5	0.14	71.3
8	5.4	140.2	0.165	71.3
10	5.4	138.2	0.210	71.3
14	5.3	140.0	0.295	69.9
18	5.3	136.4	0.435	69.9

Experimental results

Pt3 electrode

Iav (mW/cm^2)	Isc (mA/cm^2)	r ($cc/cm^2 hr$)	η_1 (%)	η_2 (%)
69.9	0.048	0.018	0.09	0.06
70.4	0.050	0.020	0.10	0.06
70.2	0.047	0.021	0.11	0.06
70.4	0.045	0.021	0.11	0.06
70.3	0.041	0.020	0.10	0.05
70.2	0.040	0.020	0.10	0.05
70.2	0.046	0.020	0.10	0.06

Table C.19

(Continued)

Pt2 electrode

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_1 (%)	η_2 (%)
69.9	0.061	0.018	0.09	0.08
69.5	0.060	0.020	0.10	0.07
69.2	0.059	0.026	0.13	0.07
69.4	0.059	0.030	0.15	0.07
69.2	0.058	0.029	0.15	0.07
68.9	0.054	0.029	0.15	0.07
69.4	0.058	0.025	0.13	0.07

Pt1 electrode

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_1 (%)	η_2 (%)
70.8	0.089	0.049	0.24	0.11
70.9	0.088	0.041	0.20	0.11
71.0	0.083	0.037	0.28	0.10
71.1	0.082	0.037	0.18	0.10
71.1	0.082	0.037	0.18	0.10
70.5	0.082	0.043	0.21	0.10
70.8	0.081	0.041	0.20	0.10

Table C.20

Experimental data

TiO_2 electrode area 33.9 cm^2

Biased photocells

Pt3 electrode

Time (min)	V_I (mV)	V3 (V)	H_2volume (cc)	Ia (mW/cm^2)	V_b (V)
4	5.4	0.226	0.125	71.3	0.46
6	5.4	0.217	0.195	71.3	0.44
8	5.4	0.217	0.265	71.3	0.44
10	5.4	0.211	0.335	71.3	0.43
14	5.5	0.199	0.470	72.6	0.43
18	5.5	0.193	0.620	72.6	0.43

Pt2 electrode

Time (min)	V_I (mV)	V3 (V)	H_2volume (cc)	Ia (mW/cm^2)	V_b (V)
4	5.1	0.214	0.095	67.3	0.45
6	5.1	0.218	0.180	67.3	0.44
8	5.1	0.212	0.225	67.3	0.44
10	5.0	0.210	0.375	66.0	0.43
14	4.9	0.215	0.460	64.7	0.42
18	4.9	0.210	0.570	64.7	0.42

Table C.20

(Continued)

Pt1 electrode

Time (min)	V_I (mV)	V3 (V)	H_2volume (cc)	Ia (mW/cm^2)	V_b (V)
2	5.4	0.291	0.06	71.3	0.45
4	5.4	0.290	0.175	71.3	0.43
6	5.3	0.280	0.265	69.9	0.43
8	5.3	0.279	0.345	69.9	0.42
14	5.3	0.268	0.545	69.9	0.42

Experimntal results

Pt3 electrode

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r ($cc/cm^2 hr$)	η_4 (%)
71.3	0.128	0.057	0,14
71.3	0.128	0,059	0.14
71.3	0.124	0,059	0.14
71.3	0.124	0,060	0.14
71.4	0.117	0,059	0,13
71.5	0.114	0.061	0,13
71.4	0,124	0.058	0,14

Table C.20

(Continued)

Pt2 electrode

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r ($cc/cm^2\,hr$)	η_4 (%)
67.3	0.127	0.063	0.15
67.3	0.126	0.052	0.15
67.3	0.129	0.053	0.15
66.0	0.125	0.050	0.15
67.3	0.124	0.066	0.15
64.7	0.124	0.056	0.14
67.0	0.127	0.057	0.15

Pt1 electrode

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r ($cc/cm^2\,hr$)	η_4 (%)
71.3	0.172	0.053	0.19
71.3	0.171	0.077	0.19
69.9	0.165	0.078	0.18
69.9	0.165	0.076	0.19
69.9	0.158	0.069	0.18
70.6	0.169	0.071	0.19

Table C.21

Experimental data

TiO_2 electrode area 33.9 cm^2

Pt3 electrode area 0.28 cm^2

Time(min)	VI(mV)	H_2volume(cc)	Ia(mW/cm^2)
5	3.5	0.05	46.2
8	4.1	0.09	54.1
12	4.2	0.13	55.4
14	4.2	0.16	55.4
16	4.1	0.18	54.1

Pt2 electrode area 0.45 cm^2

Time(min)	VI(mV)	H_2volume(cc)	Ia(mW/cm^2)
6	3.9	0.08	51.5
8	3.9	0.105	51.5
11	3.9	0.130	51.5
13	3.8	0.145	50.2
16	3.7	0.180	48.8
18	3.7	0.210	48.8

Table C.21

(Continued)

Pt1 electrode area 0.99 cm^2

Time (min)	V3 (mV)	H_2 volume (cc)	Ia (mW/cm^2)
4	4.0	0.055	52.8
6	5.9	0.065	51.5
11	3.9	0.155	51.5
14	3.8	0.205	50.1
16	3.8	0.270	50.1
20	3.7	0.300	48.8

Experimental results

Pt3 electrode

Iav (mW/cm^2)	r ($cc/cm^2/\eta$)	η_1 (%)
50.1	0.018	0,13
50.1	0.020	0.14
51.7	0.019	0.13
52.2	0.020	0,14
52.4	0,020	0,13
50.9	0.020	0,14

Table C.21

(Continued)

Pt_2 electrode

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
51.5	0.023	0.16
51.5	0.023	0.16
51.5	0.021	0.15
51.1	0.020	0.15
50.9	0.020	0.14
50.8	0.020	0.15
51.2	0.021	0.15

Pt1 electrode

Iav(mW/cm^2)	r($cc/cm^2 hr$)	η_1(%)
53.2	0.024	0.16
52.5	0.022	0.15
52.4	0.025	0.16
51.8	0.026	0.18
51.6	0.029	0.20
51.2	0.026	0.18
52.5	0.025	0.17

Table C.22

Experimental data

Pt electrode area 0.99 cm^2

TiO_2 electrode 11.6 cm^2

Time(min)	V_I(mV)	H_2volume	Ia(mW/cm^2)
2	5.2	0.025	68.6
4	5.2	0.050	68.6
6	5.2	0.070	68.6
8	5.3	0.100	69.9
TiO_2 electrode 22.3 cm^2			
2	5.2	0.040	68.6
4	5.2	0.090	68.6
6	5.1	0.145	67.3
8	5.2	0.200	68.6
TiO_2 electrode 33.9 cm^2			
2	5.2	0.03	68.6
4	5.2	0.075	68.6
6	5.2	0.130	68.6
8	5.1	0.170	67.3

Table C.22

(Continued)

Experimental results

TiO$_2$ electrode 11.6 cm^2

Iav(mW/cm^2)	r(cc/cm^{2}hr)	η_1(%)
68.6	0.052	0.27
68.6	0.065	0.33
69.0	0.060	0.31
68.6	0.065	0.33
68.6	0.060	0.31

TiO$_2$ electrode 22.3 cm^2

Iav(mW/cm^2)	r(cc/cm^{2}hr)	η_1(%)
68.6	0.054	0.28
68.6	0.060	0.31
68.3	0.065	0.36
68.3	0.067	0.35
68.5	0.061	0.32

TiO$_2$ electrode 33.9 cm^2

Iav(mW/cm^2)	r(cc/cm^{2}hr)	η_1(%)
67.9	0.026	0.14
68.2	0.033	0.17
68.3	0.038	0.20
68.1	0.038	0.20
67.9	0.034	0.18

Table C.23

Experimental data

Ptl electrode area 0.45 cm^2

TiO_2 electrode 33.9 cm^2

Time(min)	V_I(mV)	H_2volume	Ia(mW/cm^2)
2	5.3	0.01	69.9
4	5.2	0.05	68.6
6	5.2	0.10	68.6
9	5.3	0.21	69.9
TiO_2 electrode 22.3 cm^2			
2	5.2	0.045	68.6
4	5.3	0.085	69.9
6	5.3	0.135	69.9
8	5.3	0.170	69.9
TiO_2 electrode 11.6 cm^2			
2	5.3	0.03	69.9
4	5.3	0.06	69.9
6	5.3	0.09	69.9
8	5.2	0.125	68.6

Table C.23

(Continued)

Experimental results

TiO$_2$ electrode 33.9 cm^2

Iav(mW/cm^2)	r(cc/cm^{2}hr)	η_1(%)
69.6	0.020	0.11
69.2	0.022	0.11
69.0	0.029	0.15
68.9	0.041	0.21
68.9	0.029	0.15

TiO$_2$ electrode 22.3 cm^2

Iav(mW/cm^2)	r(cc/cm^{2}hr)	η_1(%)
68.6	0.061	0.31
69.2	0.057	0.29
69.5	0.060	0.31
69.6	0.057	0.29
69.3	0.059	0.30

TiO$_2$ electrode 11.6 cm^2

Iav(mW/cm^2)	r(cc/cm^{2}hr)	η_1(%)
69.9	0.077	0.39
69.9	0.077	0.39
69.9	0.077	0.39
69.6	0.080	0.40
69.8	0.078	0.39

Table C.24

Experimental data

TiO_2 electrode area 16.6 cm^2

Stirred solution of catholyte

Ag electrode area 0.80 cm^2

Time(min)	V_I(mV)	V3(mV)	H_2volume(cc)	Ia(mW/cm^2)
5	2.5	21.2	0.010	33.6
10	4.8	29.2	0.020	63.3
15	4.8	26.5	0.035	63.3
20	1.8	19.0	0.040	23.7
Au electrode area 0.80 cm^2				
5	3.1	33.6	0.01	40.4
10	5.0	37.5	0.025	66.0
15	4.9	35.8	0.040	64.7
20	4.7	33.6	0.065	62.0

Ptl electrode area 0.99 cm^2

Time(min)	V_I(mV)	V3(mV)	H_2volume(cc)	Ia(mW/cm^2)
5	6.1	98.2	0.14	80.5
12	6.3	97.9	0.30	83.1
16	6.3	97.3	0.40	83.1
18	6.4	97.1	0.54	84.5

Table C.24

(continued)

Ptl electrode area 0.99 cm^2

Time(min)	V_I(mV)	V3(mV)	H_2volume(cc)	Ia(mW/cm^2)
3	6.4	104.5	0.135	84.5
5	6.5	101.9	0.175	85.8
8	6.4	100.2	0.240	84.5
11	6.5	99.2	0.305	85.8
5	5.4	70.5	0.110	70.6
10	5.3	68.9	0.210	69.9
15	5.3	68.8	0.310	69.9
18	5.2	68.0	0.365	68.6

Au electrode area 0.80 cm^2

Time(min)	V_I(mV)	V3(mV)	H_2volume(cc)	Ia(mW/cm^2)
5	6.3	42.1	0.015	83.1
10	6.3	41.2	0.045	83.1
15	6.3	39.6	0.080	83.1
18	6.3	39.0	0.105	83.1

Table C.24

(continued)

Au electrode area 0.8 cm^2

Time (min)	V_I (mV)	V3 (mV)	H_2 volume (cc)	Ia (mW/cm^2)
5	6.5	49.5	0.035	85 8
7	6.5	47.0	0.055	85.8
10	6.4	45.6	0.065	84.5
12	6.5	44.1	0.085	85.8
5	5.4	29.1	0.015	71.3
10	5.3	24.9	0.045	69.9
14	5.3	24.8	0.060	69.9
18	5.3	23.2	0.080	69.9

Experimental results

Ag electrode

Iav (mW/cm^2)	I_{sc} (mA/cm^2)	r (cc/cm^2hr)	η_1 (%)	η_2 (%)
33.6	0.026	0.007	0.07	0.09
43.5	0.035	0.007	0.07	0.05
48.5	0.032	0.008	0.06	0.04
42.2	0.023	0.007	0.06	0.011
42.3	0.030	0.007	0.06	0.017

Table C.24

(continued)

Au electrode

Iav(mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^{2}hr)	η_1(%)	η_2(%)
40.4	0.040	0.007	0.09	0.08
48.9	0.045	0.009	0.09	0.08
52.9	0.043	0.009	0.07	0.07
55.1	0.040	0.011	0.08	0.06
52.1	0.042	0.009	0.08	0.07

Ptl electrode

Iav(mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^{2}hr)	η_1(%)	η_2(%)
80.5	0.118	0.101	0.44	0.12
80.5	0.118	0.088	0.39	0.12
81.4	0.117	0.078	0.34	0.12
81.8	0.117	0.094	0.41	0.12
82.3	0.118	0.090	0.40	0.12
84.5	0.126	0.122	0.51	0.14
84.5	0.123	0.105	0.44	0.13
84.9	0.121	0.108	0.45	0.13
84.8	0.119	0.100	0.42	0.13
85.0	0.123	0.109	0.46	0.13

Table C.24

(Continued)

Experimental results

Pt3 electrode area 0.28 cm^2

TiO_2 electrode area 21.6 cm^2

Iav(mW/cm^2)	r(cc/cm^2hr)	η_1(%)
69.9	0.078	0.39
69.9	0.071	0.36
70.2	0.060	0.30
70.5	0.068	0.34
70.1	0.069	0.35

TiO_2 electrode area 22.3 cm^2

Iav(mW/cm^2)	r(cc/cm^2hr)	η_1(%)
69.9	0.020	0.10
69.9	0.020	0.10
70.2	0.031	0.16
70.1	0.030	0.15
70.0	0.026	0.13

TiO_2 electrode area 33.9 cm^2

Iav(mW/cm^2)	r(cc/cm^2hr)	η_1(%)
70.4	0.029	0.14
70.2	0.029	0.15
70.2	0.028	0.14
70.4	0.028	0.14
70.3	0.028	0.14

Table C.24

Experimental data

Pt3 electrode area 0.28 cm^2

TiO_2 electrode 11.6 cm^2

Time(min)	V_I(mV)	H_2volume(cc)	Ia(mW/cm^2)
2	5.3	0.03	69.9
4	5.3	0.035	69.9
6	5.3	0.070	71.3
8	5.4	0.105	71.3
TiO_2 electrode 22.3 cm^2			
2	5.3	0.015	69.9
4	5.3	0.030	69.9
6	5.4	0.070	71.3
9	5.3	0.100	69.9
TiO_2 electrode 33.9 cm^2			
4	5.4	0.035	71.3
6	5.3	0.075	69.9
8	5.3	0.100	69.9
10	5.4	0.165	71.3
12	5.4	0.195	71.3

Table C.24

(continued)

Ptl electrode

Iav(mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^2hr)	η_1(%)	η_2(%)
70.6	0.085	0.079	0.40	0.10
70.2	0.083	0.074	0.37	0.10
69.9	0.082	0.073	0.37	0.10
70.2	0.084	0.075	0.38	0.10

Au electrode

Ia (mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^2hr)	η_1(%)	η_2(%)
83.1	0.051	0.010	0.04	0.05
83.1	0.049	0.016	0.07	0.05
83.1	0.048	0.024	0.10	0.05
83.1	0.047	0.021	0.09	0.05
83.1	0.049	0.018	0.08	0.05
85.8	0.059	0.025	0.10	0.06
85.8	0.056	0.028	0.11	0.06
85.5	0.055	0.023	0.10	0.06
85.3	0.053	0.026	0.10	0.05
85.6	0.057	0.026	0.10	0.06

Table C.24

(continued)

Au electrode

Iav(mW/cm^2)	I_{sc}(mA/cm^2)	r(cc/cm^{2}hr)	η_1(%)	η_2(%)
71.3	0.035	0.011	0.05	0.04
70.8	0.030	0.016	0.08	0.04
70.6	0.030	0.015	0.07	0.04
70.5	0.028	0.016	0.08	0.03
70.9	0.032	0.015	0.07	0.04

Table C.25

Experimental data

TiO_2 electrode are 33.9 cm^2

Non-stirred solution of catholyte

Ag electrode area 0.80 cm^2

Time(min)	V_I(mV)	V_3(mV)	H_2volume(cc)	Ia(m/W/cm^2)
2	3.1	30.7	0.01	40.9
4	3.5	32.8	0.01	46.2
6	3.5	33.2	0.025	46.2
8	3.5	32.7	0.035	46.2
10	3.0	30.2	0.050	39.6
12	1.0	25.3	0.060	14.5

Pt electrode area 0.99 cm^2

Time(min)	V_1(mV)	V_3(mV)	H_2volume(cc)	Ia(mW/cm^2)
2	4.0	122.0	0.01	52.8
4	4.0	110.0	0.055	52.8
6	3.9	108.3	0.065	51.5
8	3.9	107.5	0.100	51.5
12	3.8	103.5	0.165	50.1

Table C.25

(Continuced)

Experimental results

Ag electrode

Iav(mW/cm^2)	Isc(mA/Cm^2)	r(cc/cm^2hr)	η_1(%)	η_2(%)
40.9	0.018	0.009	0.07	0.04
44.8	0.019	0.001	0.01	0.04
45.2	0.021	0.004	0.01	0.04
45.4	0.019	0.007	0.06	0.04
44.4	0.018	0.008	0.06	0.04
40.2	0.015	0.009	0.08	0.04
44.5	0.019	0.009	0.04	0.04

Pt_1 electrode

Ia(mW/cm^2)	Isc(mA/cm^2)	r(cc/cm^2hr)	η_1(%)	η_2(%)
53.4	0.072	0.009	0.06	0.12
53.2	0.065	0.024	0.16	0.11
82.8	0.064	0.019	0.13	0.11
52.5	0.063	0.022	0.15	0.10
52.0	0.061	0.024	0.16	0.10
52.9	0.066	0.021	0.14	0.11

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VITA

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